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All correspondence relating to the publication of papers should be addressed to

Harry E. Jordan, Secretary—500 Fifth Avenue, New York 18, N.Y.

ERIC F. JOHNSON, *Editor* — LAWRENCE FARBER, *Associate Editor*

DANIEL N. FISCHEL, *Managing Editor* — ELIZABETH P. MCSHERRY, *Associate Editor*

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Cathodic Protection of Buried Metallic Structures Against Corrosion

Correlating Committee on Cathodic Protection

This is Bulletin Number One, the first of a series to be prepared by the Correlating Committee on Cathodic Protection. H. H. Anderson, Chairman.

CORROSION of buried plant and its contingent losses are costing American industry about a billion dollars per year. Much of this loss can be stopped by proper preventive measures.

These enormous losses and the problems of preventing them are shared in different form and degree by all operators of water, gas and oil lines; communications, signal and power cables; rail tracks; tanks; equipment foundations; and other metallic structures buried or in contact with the soil or water.

Corrosion of buried structures is simply a chemical attack by nature which attempts to revert refined metals to their original form as ores or compounds. This chemical attack always accompanies a flow of electric current from the metal. Usually a chemical attack causes the current flow, but, conversely, a flow of impressed current from metal into soil causes chemical attack. If such current outflow can be prevented, corrosion cannot occur.

Regardless of whether the attack initiates the current flow or vice versa, the corrosion damage is physically similar; and a current outflow of 1 amp. in one year accompanies a loss of as much as 20 lb. of iron or steel, or 70 lb. of lead.

Corrosion prevention properly starts with the design of structures and equipment, including the selection and placement of materials—in particular, avoiding the contact of dissimilar metals—so as to minimize corrosion possibilities. During plant construction and subsequent operation, much corrosion can be prevented by avoiding the disposal of waste matter where it may unnecessarily pollute the soil in or near the plant. In concentrated operating areas, effective surface drainage will minimize the likelihood of soil pollution.

Stray Currents

The attention of industry was directed, even before 1900, to the corrosion of buried pipe and cable near

electrified street-railway tracks by the currents which "strayed" into these structures from the rails. The pipes and cables were corroded where these currents left them via the soil enroute back to the current source. This type of corrosion is called "electrolysis."

Joint engineering committees in many metropolitan areas, through a fine spirit of cooperation, have effectively minimized the damage due to stray-current electrolysis. The customary technique is to keep the stray currents as low as possible, and to provide continuous metallic paths through which they will flow back to their source.

Though not initially recognized as beneficial, these currents, when strong enough, stopped corrosion where they strayed into the other structures because they prevented the outflow of the weaker currents attending such corrosion. This electrical counteraction is the basis of the rapidly developing technique of cathodic protection.

In numerous areas where transit companies have abandoned electrified track, operators of other structures are finding that the removal of the stray railway currents has allowed the weaker currents of natural corrosion to flow unopposed. The cathodic protection before provided in various degrees by the stray currents has been removed!

Protective Coatings

Outside of the geographically small metropolitan areas, different problems are presented. Corrosion of buried structures is widespread unless it is prevented. Among the accepted preventive techniques are properly engineered coatings or cathodic protection, or a combination of the two.

If a structure could be coated with an impervious and durable layer of electric insulating material, all flow of current to or from the soil would be prevented. Inasmuch as the soil and moisture would be separated from the structure, corrosion could not occur.

Although excellent coatings now are available that will provide reasonable protection if carefully applied, most of them will deteriorate or become damaged in time. Such coating defects tend to focus corrosive action and hasten structure damage locally.

Early structures were buried bare, and many coatings applied on other structures prior to the last decade have little if any protective value now. To coat or recoat these operating structures—which usually requires that they be uncovered, raised and cleaned—is difficult and expensive, and often impractical.

Types of Protective Currents

For reducing corrosion on older structures, or insuring continued protection with newer coatings, the use of cathodic protection is indicated. Specifically, this is the technique of impressing inward-flowing currents to counteract, and thus prevent, the outward-flowing currents of natural corrosion. Where cathodic protection is applicable, it has the special advantage that it can be installed with very little disturbance of the structures.

To apply cathodic protection requires continuous supplies of protective current. It also requires the burial—in suitable ground beds at appropriate distances from the structure—of one or more masses of metal or carbon (called "anodes") through which this current can be introduced into the soil. For this current to serve

its purpose as it fans out through the soil and distributes itself along the structure, it must be of sufficient strength or density to enter the structure and counteract the harmful corrosion currents.

Two types of protective current source may be used. Where considerable current is required, it may be obtained from direct-current generators or rectifiers connected by insulated wires positively to the anodes and negatively to the structure. For the introduction of external currents through the soil into the structure, anodes of graphite rods, or of scrap cast iron or steel, are customarily used.

Where less protective current will suffice, anodes can be used which will self-generate the needed current. When masses of magnesium, aluminum or zinc are buried and connected to a steel or lead structure by insulated wires, they will generate current (as in a battery) which will flow through the soil into the structure.

All types of anodes will be corroded by the protective current which they discharge to the soil, and they must be renewed at intervals. Under favorable conditions, however, these anodes may last several years before replacement is necessary.

Interference

Some of the current introduced at the anodes to protect one structure cathodically may enter a neighboring structure and traverse it for a distance while enroute to the protected one. Where this current leaves the neighboring structure and enters the soil, corrosion occurs which is similar to street-railway stray-current electrolysis. It can be prevented in several ways, one of the commonest of which is to connect the neighboring structure to the protected one by a wire "drainage bond" of proper resistance.

Because of this possibility of interference, any operator planning a cathodic protection installation should notify operators of neighboring buried structures so that all concerned can appraise the interaction problems. Experience shows that these can be dealt with most effectively and satisfactorily through cooperative study and tests by the engineers of the operators involved.

Joint Systems

The foregoing paragraph applies to conditions where cathodic protection is designed primarily for the structure (or structures) of a single operator. Frequently, however, where reasonably adjacent structures of two (or more) operators are subject to similar corrosion damage, "joint cathodic protection systems" can be designed, installed and operated economically to the benefit and satisfaction of all concerned.

The fundamentals of cathodic protection are relatively simple, but the solution of its technical and economic problems requires a high degree of engineering skill. The harmony in which metropolitan engineers have coordinated their complex electrolysis problems sets the pattern for the cooperation needed to deal with local cathodic protection problems in the field. These call for a business judgment by all concerned, and an approach based on mutual appreciation of the obvious equities and resultant benefits.

The use of cathodic protection offers widespread opportunities for reducing the enormous losses incident to underground corrosion, and its application requires cordial intercompany rela-

tions. Thus it is good business for all managers of buried plant to be generally informed about, and to give sympathetic support to their engineers dealing with, the application of cathodic protection.

Future Bulletins

The basic objective of the eleven nationwide organizations * sponsoring this bulletin is to promote better understanding of cathodic protection and to foster the needed cooperation among operators of all types of buried structures in its beneficial application. To this end, each organization will promulgate this and later bulletins of the Correlating Committee on Cathodic Protection in its own format to its own members.

The Correlating Committee on Cathodic Protection is preparing three other bulletins. Number Two will define a practical procedure for inter-operator notification, Number Three will assist corrosion engineers in the technical aspects of cathodic protection coordination and Number Four will treat "joint systems." This general committee will, however, refrain from dealing with individual local problems which may develop.

* These include the Assn. of American Railroads, American Gas Assn., American Petroleum Inst., American Public Works Assn., American Water Works Assn., Edison Elec. Inst., Intl. Municipal Signal Assn., U.S. Independent Telephone Assn., Bell Telephone Companies, Western Union Telegraph Co. and Natl. Assn. of Corrosion Engrs. Chairman of the Correlating Committee is H. H. Anderson, Shell Pipe Line Corp., Houston, Tex. A.W.W.A. members serving on the committee are: Frank E. Dolson Jr., Dist. Engr., St. Louis County Water Co., and Secretary, Correlating Committee on Cathodic Protection; Albert R. Davis, Supt., Water Dept., Austin, Tex.; and Wendell R. LaDue, Supt. and Chief Engr., Bur. of Water and Sewerage, Akron, Ohio (representing the American Public Works Assn.).

Principles of Cathodic Protection Design

By L. P. Sudrabin and Frank P. Macdonald

A paper presented on Nov. 20, 1947, at the Joint Meeting of the Cuban and Florida Sections, St. Petersburg, Fla., by L. P. Sudrabin, Chem. Engr., and Frank P. Macdonald, Sales Mgr., Electro Rust-Proofing Corp., Belleville, N.J.

A SUBSTANTIAL proportion of the reported six billion dollar annual cost of all types of corrosion (1) is borne by the water works industry in steel water tanks, filtration and softening plant equipment, pipelines and other structures in distribution systems. Shortened structure life, increased maintenance costs and greater out-of-service time are all commonly encountered forms of rust and corrosion damage.

The National Association of Corrosion Engineers (1) lists four main corrosion controlling techniques: (1) cathodic protection, (2) metallic coatings, (3) inorganic and organic coatings and (4) alloying. Other means include metal purification, alteration of the environment and the use of passivators and inhibitors. Of all these, according to corrosion engineers, cathodic protection is the most effective single method, as it surmounts the shortcomings of other protective measures; and when used in conjunction with paint or other coatings, its advantages in both economy and corrosion control become even more apparent.

That the process is basically sound and of economic value in controlling the wastage of metal from water works structures is now generally accepted. This is evidenced by its growing application, by the results of the detailed study and investigation being pursued by technical men throughout the country and by its acceptance by the American Water Works Association, the Associated Factory Mutual Fire Insurance Companies and other similar authoritative organizations.

Basic Principles

For many years the prevention of rust and corrosion on submerged metal surfaces was almost exclusively the province of paint and other coatings, yet these coatings alone are completely effective only when perfectly applied and maintained, a condition that is almost impossible of accomplishment. Any pinholes, scratches or breaks in the barrier film—resulting, for example, from ice damage in water storage tanks or backfilling of pipelines—may concentrate the normal corrosion activity of a large area at these "holidays," thus leading to rapid penetration of the metal at the exposed area (2). In addition, the natural deterioration of the film requires continuous patching or renewal, which, because of inaccessibility, is expensive and inconvenient. As a result of these shortcomings, industry revived some old principles and put them to work in what is now known as cathodic protection. This method is effective

alone or it may be used in conjunction with paint or other coatings to police the inevitable breaks in the coating. The design employed on any particular cathodic protection application, however, must consider the economic factors involved, if the resulting installation is to meet successfully the requirements of complete protection, maximum economy and freedom from operating difficulties.

The corrosion of iron was shown by W. R. Whitney and others, as early as 1903, to be electrochemical (3). Corroding metal surfaces contain innumerable local galvanic cells, or "corrosion batteries," in which the corrosion takes place. These "batteries" are the result of metallic surface areas of differing electrical potential, which form the anodes and cathodes while the water or soil in contact with the surface acts as an electrolyte (4). The "corrosion battery" behaves like an ordinary voltaic cell, and as the current flows from the anodic to the cathodic area metallic ions are released into solution at the anode, resulting in rust and pitting.

The possibility of stopping the escape of metallic ions by electrically preventing the flow of current from the metal was first demonstrated in 1824 by Sir Humphrey Davy (5). The great value of this method lies in its simplicity and direct effectiveness, as demonstrated by the "cathodic protection battery," which is similar to the corrosion battery except that an auxiliary anode acts as a substitute for the local anode on the metal surface being protected.

The auxiliary anodes may be either electrolytic (energized by an external source of direct current) or galvanic (composed of a metal higher in the electromotive series than the metal to be protected). In either case, the electric current flowing from the auxiliary anodes to the structure to be protected prevents the flow of current from the anodic to the cathodic areas on the protected surface, and the escape of metallic ions from the local cell anodes ceases.

General Design Considerations

The detailed design of a particular system requires, first, careful consideration of its environmental characteristics and, second, the selection and arrangement of equipment to meet the problem imposed by these characteristics adequately.

Perhaps the most important single consideration in designing cathodic protection systems for water works structures is the effect of water characteristics and changes in these characteristics. The determination of the correct facts and the proper evaluation of the available data require—more than does any other single phase of the problem—the guidance of a qualified cathodic protection engineer.

From generally available data a picture may be gained of the average conditions likely to be encountered in any geographic section, such as the usual source of supplies, whether ground or surface, the average hardness, alkalinity, total solids, etc. This general information, however, though useful as a guide and over-all check, is of little help in evaluating the problem to be met on a specific job. In Illinois, for example, the figure given for average hardness is 148 ppm. with a variation from an average of 127 ppm. for surface supplies to 345 ppm. for ground water. Yet these average figures include such variations as a well at Aurora with a total dissolved solids content of 821 and a hardness

of 534 ppm.; at the other extreme, a filtered and softened surface water at Bloomington has a total solids content of 108 and a hardness of 77 ppm. These extremes indicate the risk of bad design taken by the cathodic protection engineer who relies on average statistics alone.

Even where average figures are given for a single municipal supply, the possibilities of error are large, unless detailed information is available on the source and physical arrangement of the system and the type and degree of treatment.

An example of what can happen in a single water system because of variation in chemical content is provided by this case history: A cathodic protection system, designed in accordance with a complete *delivered* water analysis, was installed for the protection of the water storage tank in a small town in Tennessee. For some months the system operated satisfactorily, and then it suddenly began blowing fuses no matter how much the voltage was reduced. The rectifier unit was examined and found perfect and there were no shorts or grounds in the wiring between the rectifier and the anodes. Another water sample was analyzed which showed increased conductivity beyond the range of the original design. Upon further investigation it was learned that the tank was normally filled with water from two wells, but, during certain seasons when the demand was great, a third well producing water with a high dissolved solids content was called into service, thus greatly increasing the total dissolved solids content of the entire delivered water supply. This condition of varying conductivity, not known originally, was subsequently overcome by inserting a variable resistance in the anode circuit for use when water from the third well was pumped into the tank.

This extreme instance is given simply to indicate the extent of possible error if correct, up-to-date and detailed knowledge of the water characteristics of the supply being considered is not taken into account.

Recent, careful and complete analysis, moreover, does not in itself solve the designer's problem. Seasonal changes in the raw water source or radical changes in the treatment processes, for example, may alter the characteristics of the water so greatly that the corrosive condition to be corrected by the cathodic process becomes entirely different. Thus it behooves the designer not only to exercise the utmost diligence in analyzing the conditions present at any particular time, but also to essay the role of prophet and attempt to foresee the variations which may be introduced by seasonal changes, by periods of reservoir turnover, or by occasionally radical changes in chemical composition due to the introduction of industrial wastes and byproducts.

This is emphasized by the fact that so many of the characteristics of any water—dissolved solids, hardness, dissolved oxygen, chloride content, pH, specific resistance—govern the design of the cathodic protection system. The anode configuration in a tank containing New England water with a small amount of dissolved solids would be entirely different from that in the same tank containing water from the midwest with its high dissolved solids content. Since the conductivity of the water is almost directly proportional to the dissolved solids content, the anodes in the tank containing New England water must be placed close

to the surfaces to be protected in order to obtain the prescribed amperage without the use of excessive voltage. The anodes in the tank containing midwestern water can be placed further away from the submerged surfaces and therefore will be fewer in number.

In addition, many other considerations influence cathodic system design and maintenance. For instance, temperature, which is a physical factor, must be considered in dealing with water-storage vessels. Because of the greater corrosiveness of high-temperature waters, provision must be made for the application of higher current densities to the containing vessel. Furthermore, anodes that will fail mechanically or that will produce objectionable oxides when exposed to high temperatures cannot be used, and anode supports must be made of insulating material that will withstand the higher temperatures.

Selection of Equipment

Basically, a cathodic protection installation for a water works structure, such as an elevated storage tank or clarifier, consists of a great deal of engineering and a relatively small amount of equipment. The equipment will include a rectifier (if electrolytic anodes are used), an anode system and various cables, fittings and so forth. The type and size of rectifier selected depends entirely on the current density necessary to protect the submerged metal surface and the physical conditions under which the rectifier is to be installed. The type, size and spacing of anodes is predicated, first, on the necessity of distributing the protective current to all parts of the structure under corrosive attack and, second, upon such physical considerations as the size and shape of the structure, water characteristics and temperature.

Current density requirements vary widely from as low as 0.2 to as high as 20 ma. per square foot, and, just as any surface coating to be effective must be applied over the entire metal surface, so must the protective current density be distributed over the entire submerged surface. To achieve proper distribution of the applied current, the location of the anodes and their length and diameter must all be considered.

It is sometimes advisable in large tanks with relatively greater bottom areas to place the anodes in a horizontal position. At times both vertical and horizontal anodes are indicated. Where only vertical anodes are used, they must be long enough to distribute an adequate current density to the floor. In elevated tanks having large-diameter steel riser pipes, good design should provide a separate full-length anode in the riser pipe with current supplied to the riser anode from a separate circuit in the rectifier. The advisability of providing an anode extending throughout the riser pipe is indicated by studies (6) on current density distribution in a tube where the current density dropped below the protective value immediately beyond the influence of the anode. This is also verified by studies reported by Hoover (7) at Columbus, Ohio, on the corrosion of hot water tanks, which included cathodic protection. The tanks had complete cathodic protection within the area of influence of the anode.

The selection of an anode material offers many choices, but, in general, it may be said that electrolytic anodes may be either of the expendable or nonsacrificial type, both energized by an external source of direct current.

The expendable anode materials may be iron, carbon steel, chrome steel, aluminum, etc., and the nonsacrificial materials include carbon, graphite and platinum.

The low electrochemical equivalent, light weight, ease of handling and uniformity of corrosion attack of certain aluminum alloys usually make them the most satisfactory expendable anode material.

Galvanic anodes are composed of any one of several metals higher in the electromotive series than the metal to be protected, and for this reason they are "self-energized" when electrically connected to the structure to be protected. Magnesium, aluminum and zinc are the metals usually considered as galvanic anodes.

The application of a good protective coating to the surface to be protected permits more extensive applications of galvanic anodes than would otherwise be possible.

Design Comparisons

The requirements of a cathodic protection system may be illustrated by comparing two typical examples in which all the necessary information is assumed to be known.

With a nonaggressive well water having a dissolved solids content of 372 ppm., a total hardness of 310 ppm., a D.O. content of approximately 2.0 ppm. and a specific resistance of about 1,400 ohms, an adequate design for a typical 200,000-gal. elevated tank with a 3×100-ft. riser would require one 96-ft. by $\frac{7}{8}$-in. riser anode, four 27-ft. by $1\frac{1}{4}$-in. bowl anodes on a 9-ft. radius and one 8-amp. rectifier.

The same tank, however, when storing an aggressive surface water with 89 ppm. dissolved solids, 53 ppm. total hardness, approximately 10 ppm. D.O. and a specific resistance of about 6,000 ohms, would require one 96-ft. by 1-in. riser anode, eleven 28-ft. by 1-in. bowl anodes on a 14-ft. radius, four 3-ft. by $1\frac{1}{2}$-in. bowl anodes on a 6-ft. radius and one 20-amp. rectifier.

These two examples should be compared on an economic basis, since the justification for cathodic protection, which is based on the premise that it can provide a greater degree of protection for less dollars than any other means, is an economic one. In the first of these examples, the original cost might possibly run in the neighborhood of $950 and the annual power cost, at 1¢ per kilowatt-hour, would be about $14. In the second example, the costs would be approximately $1,850 for the original installation and $35 for power.

This very considerable variation for two structures of the same size, and therefore representing essentially the same capital investment, needs examination to determine whether or not something can be done to reduce the costs of protection on the tank carrying the more aggressive water. In the first case the basic water characteristics made it possible to rely for some protection on building up a calcareous layer to obstruct the passage of oxygen to the cathodically active points on the metal surface. Since the characteristics of the water will not allow this in the second case, consideration should be given to the surface application of a mechanical barrier in the form of paint or other coating. The cathodic protection system would then have the role of a policeman keeping a constant watch on any imperfections developing in the protective barrier. Assuming two coats of red-lead or equivalent paint on the submerged surface, the cathodic protection design

would require only one 96-ft. by ¾-in. riser anode, eleven 28-ft. by ¾-in. bowl anodes on a 14-ft. radius, four 3-ft. by 1-in. bowl anodes on a 6-ft. radius and one 12-amp. rectifier.

Thus it is seen that, for aggressive water, the paint barrier serves partially the same purpose of reducing current requirements as does the calcareous film which can be "plated out" on the tank wall in the nonaggressive hard water. The cost figures in the second example would become approximately $1,200 for the original installation and $21 for operating power.

Even with nonaggressive water a paint barrier will effectively—though not so startlingly—reduce the installation and operating costs, through lowered rectifier capacity and less current usage.

Conclusion

This brief paper, while touching only the highlights of the subject, demonstrates three basic points: (1) that the principle of cathodic protection is neither new nor mysterious; (2) that the soundness of the principle can be easily explained and has been definitely demonstrated; and (3) that successful design requires the careful consideration of many factors.

Cathodic protection is no panacea for all corrosion difficulties. Nevertheless, when intelligently applied—taking into consideration all of the design-determining factors, such as water characteristics, locality, type, size and other physical aspects of the structure to be protected, and the economics of the situation—cathodic protection can effectively aid in the mitigation of one of the water works industry's most costly problems.

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Magnesium for Cathodic Protection of a Municipal Piping System

By K. D. Wahlquist and Oliver Osborn

A paper presented on Sept. 19, 1947, at the Michigan Section Meeting, Bay City, Mich., by K. D. Wahlquist, Electro Rust-Proofing Corp., and Oliver Osborn, Texas Div., Dow Chemical Co.

THE successful application of cathodic protection to the underground piping in an entire municipality is an accomplishment which would interest any corrosion or water works engineer. Such a project has actually been carried out by the use of magnesium as a galvanic anode in the city of Lake Jackson, Tex.

The ability of magnesium to halt corrosion, the theory and practice of its use, its natural advantages and its economic aspects are covered in this discussion of a proven installation at Lake Jackson. It is interesting to note that, in spite of the fact that leaks had been occurring in the water lines of Lake Jackson at an alarming rate, not a single new leak has developed since the magnesium installation was made more than a year ago.

In the early war years of 1941–42 the city of Lake Jackson was constructed almost overnight to solve a critical housing shortage for workers in near-by war plants. Sewers and utility piping were laid, streets graded and buildings erected so that in a scant twelve months' time a new and model city took its place on the Texas Gulf Coast.

All went well for about three years until, again almost overnight, something happened which would severely try the patience of any water works engineer. Miniature geysers began to spring up in the front yards all over town. Corrosive soil, war-quality galvanized pipe and a cast-iron-galvanized-iron couple between mains and service lines were causing failure of the galvanized water-service piping.

When leaks on the Lake Jackson water lines began to develop faster than a maintenance crew could repair them—eighteen leaks having been reported in about three months—it was decided by the city council that some form of remedial action must be taken immediately. Because the physical characteristics of magnesium so well qualify it for corrosion prevention, it was proposed to apply magnesium anodes to these lines to halt the rapid deterioration. In March 1946 a magnesium installation was made in a major portion of the city, and the results obtained were even beyond expectations: since the magnesium installation was completed, not one new leak has occurred.

Cathodic Protection Theory

Corrosion has long been recognized as electrochemical. For example, when iron from a buried pipe corrodes or goes into a solution, a minute electric current is generated which flows from

the corroding area to some other section of the pipe. As soon as this phenomenon was thoroughly understood, it seemed very reasonable to assume that corrosion might be stopped by passing into the corroding area a current—generated from an external source—which was greater than, and in the direction opposite to, the corrosion current. Experience proved that the theory was correct, and today this method of corrosion prevention, commonly termed cathodic protection, is widely used.

It has long been known that when two dissimilar metals are placed in a common electrolyte and connected together electrically a current will flow between them. Such a system is known as a galvanic cell. Every metal has a definite tendency to dissolve or go into solution when placed in a given electrolyte, and this tendency is technically referred to as solution potential. When two metals having different solution potentials are connected together in a common electrolyte, the metal with the greater potential will proceed to dissolve preferentially and in so doing will override or inhibit the solution of the metal having the lesser potential. This phenomenon can be explained electrochemically by the fact that the ions liberated by the dissolving particles of the metal having the higher solution potential (the anode) form an electric current which flows through the electrolyte to the metal having the lower solution potential (cathode). This current acts to inhibit the solution of the metal to which it is flowing and thus cathodically protects it.

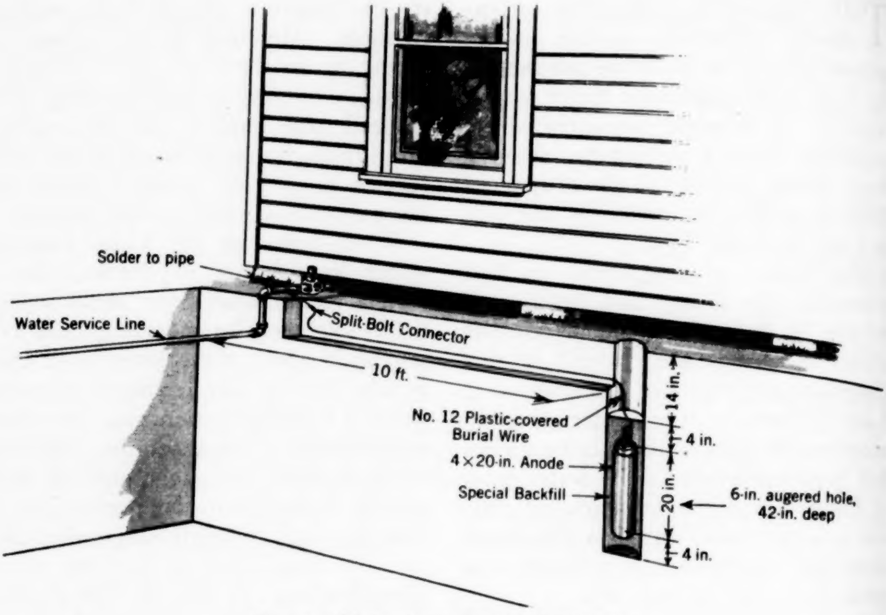

FIG. 1. Magnesium Anode Installation

As current flows from the anode to the structure to be protected, a reaction known as polarization takes place on the

surface of the structure. Polarization is caused by the electrodeposition of a film of hydrogen gas on the structure surface, and it is generally accepted by corrosion engineers that when this film of gas has been formed corrosion is halted. A simple means has been devised to detect the presence of this polarization film by measuring the solution potential of the structure with respect to some standard reference electrode. A $Cu \cdot CuSO_4$ electrode is commonly used as a reference in making this potential measurement, a value of -0.80 to -0.85 v. between this electrode and the structure being generally accepted as an indication that complete protection has been obtained. Under normal conditions, the current required to halt corrosion will vary from 1 to 3 ma. per square foot of bare steel surface to be protected.

Use of Magnesium

Magnesium, which is extracted from the sea, was such a vital material during the war years that it was not available for experimental purposes. Immediately after the war, however, the Dow Chemical Co. instigated a very extensive investigation of the possibilities of its use for cathodic protection. Because both laboratory and field results were highly successful, magnesium was at once placed on the market as a galvanic anode. The installation at Lake Jackson was the first to protect an entire municipality cathodically by this method.

The greater the difference in solution potential between the two metals, the greater will be the current flow between them. This was one of the principal factors which suggested the use of magnesium for the cathodic protection of other metals, as it has the greatest solution potential of all the commercially available anodic metals (1). Another important factor which favored the use of magnesium for cathodic protection was its high content of stored energy, the electrochemical equivalent of 1 lb. of magnesium being theoretically equivalent to 1,000 amp-hr. With these characteristics, it was believed that rods of magnesium could be buried adjacent to the structure to be protected and an electrical bond established between the two; the current produced from the resulting galvanic cell would then cathodically protect the structure. Developments revealed

TABLE 1

Calculations for Cathodic Protection Installation

Estimated pipe to be protected per pair of dwellings	
135 ft. of ¾-in. bare galvanized water line	37.1 *sq.ft.*
135 ft. of ¾-in. coated gas line (assume 1 per cent bare)	0.4
100 ft. of 4-in. coated gas main (assume 1 per cent bare)	1.2
16 ft. of 6-in. cast-iron water main*	27.7
TOTAL	66.4 *sq.ft.*
Estimated current demand for protection per square foot	1.0 *ma.*
Expected average output per 4 × 20-in. anode under given conditions	90.0 *ma.*
Number of pairs of dwellings to be protected per anode	90/66.4 = 1

* Because of the bell-and-spigot joint it was assumed that only the joint to which the service line was attached would be protected.

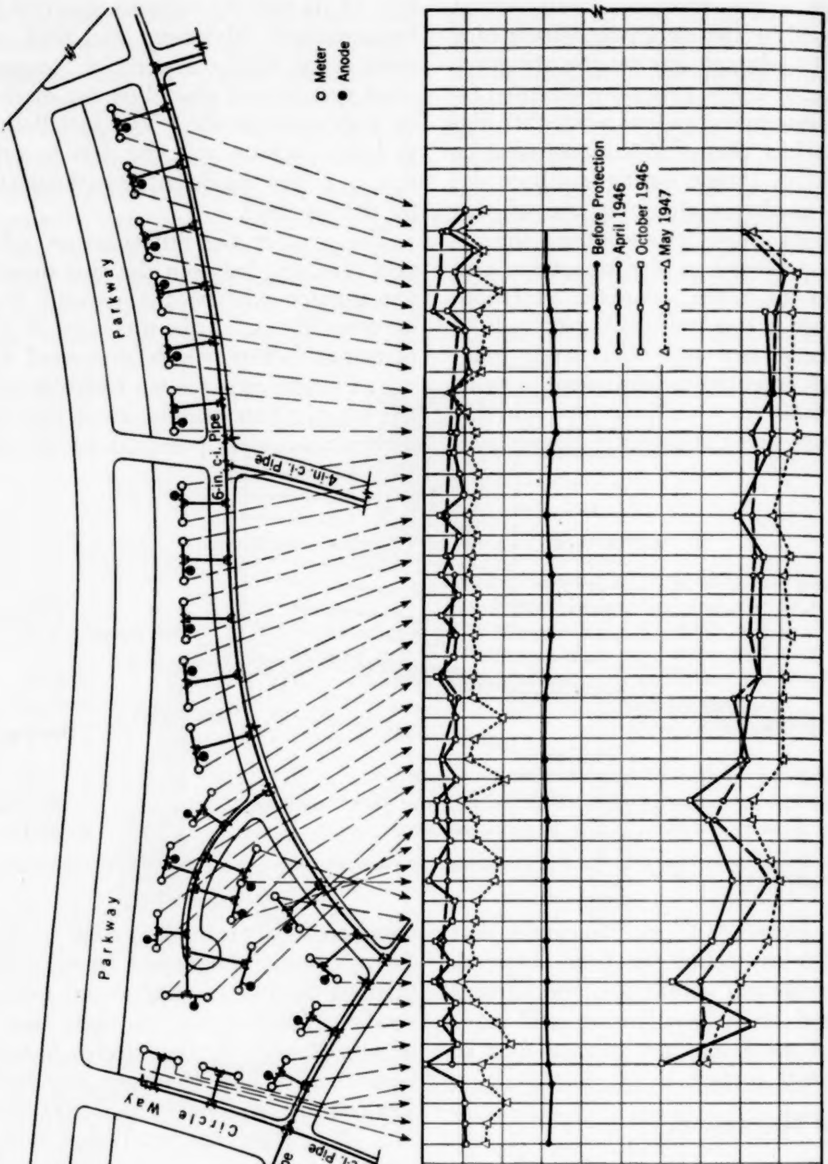

FIG. 2. Pipe-to-Soil Potential and Current Surveys on Typical Section

that a magnesium installation was practically as simple as was originally visualized.

It was also demonstrated that an alloy containing approximately 6 per cent aluminum, 3 per cent zinc and only traces of such impurities as copper, iron and nickel exhibited better over-all performance characteristics than the unalloyed, commercially pure magnesium (2).

A diagram of a typical installation is shown in Fig. 1. The magnesium anodes, which are in the form of cylindrical ingots for convenient handling, are generally placed in augered holes 3–6 ft. deep, located about 10 ft. from the structure to be protected. The holes are augered larger than the anodes in order to have a 1-in. annular space surrounding them. The space is filled with a slurry consisting of 75 per cent bentonite clay and 25 per cent gypsum.* This mixture, called a backfill, serves the dual purpose of lowering the electrical resistance between the anode and the structure and of providing a medium around the anode which will promote a greater effective yield of energy. After the slurry is placed around the anode, the final step in the installation consists of connecting preattached insulated anode wire to the structure.

This method of installation is being rapidly superseded by a packaged anode called a "Galvo-Pak," † which offers a more economical method of installation. The unit, which is furnished ready to install, consists of a 17-lb. anode packed in 25 lb. of specially prepared quick-wetting backfill with a 20-ft. wire lead attached.

* A mixture of 50 per cent bentonite, 25 per cent gypsum and 25 per cent sodium sulfate is normally used where soil resistances are above 1,000 ohms per cubic centimeter.

† Made by the Dow Chemical Co.

Design and Installation

Lake Jackson comprises a group of approximately 800 houses laid out along a series of unsymmetrically curved and interlocking streets. The water system consists of 6-in. cast-iron mains with leaded bell-and-spigot joints laid underneath the streets and ¾-in. bare galvanized service lines taking off for every pair of houses. The gas system parallels the water system and consists of coated and wrapped steel pipe, 4- and 2-in. mains, and ¾-in. service lines with all-welded joints. The physical layout is such that the two systems are electrically connected through the water heaters in each house. Individual services are electrically inter-connected through the gas mains.

In designing the Lake Jackson installation the factors which had to be determined or estimated were: (1) average soil resistivity, (2) square feet of steel (pipe) to be protected and (3) current density required to protect a unit area of steel in the given environment.

Soil resistance measurements over representative areas of the town—made with a Leeds and Northrup soil bridge and a specially designed double-electrode prod rod—were found to range from 500 to 2,500 ohms per cubic centimeter. From previous cathodic protection experience in this area, it was estimated that approximately 1 ma. per square foot of steel surface would be required for protection. In Table 1 is shown the basis on which anode requirements were calculated.

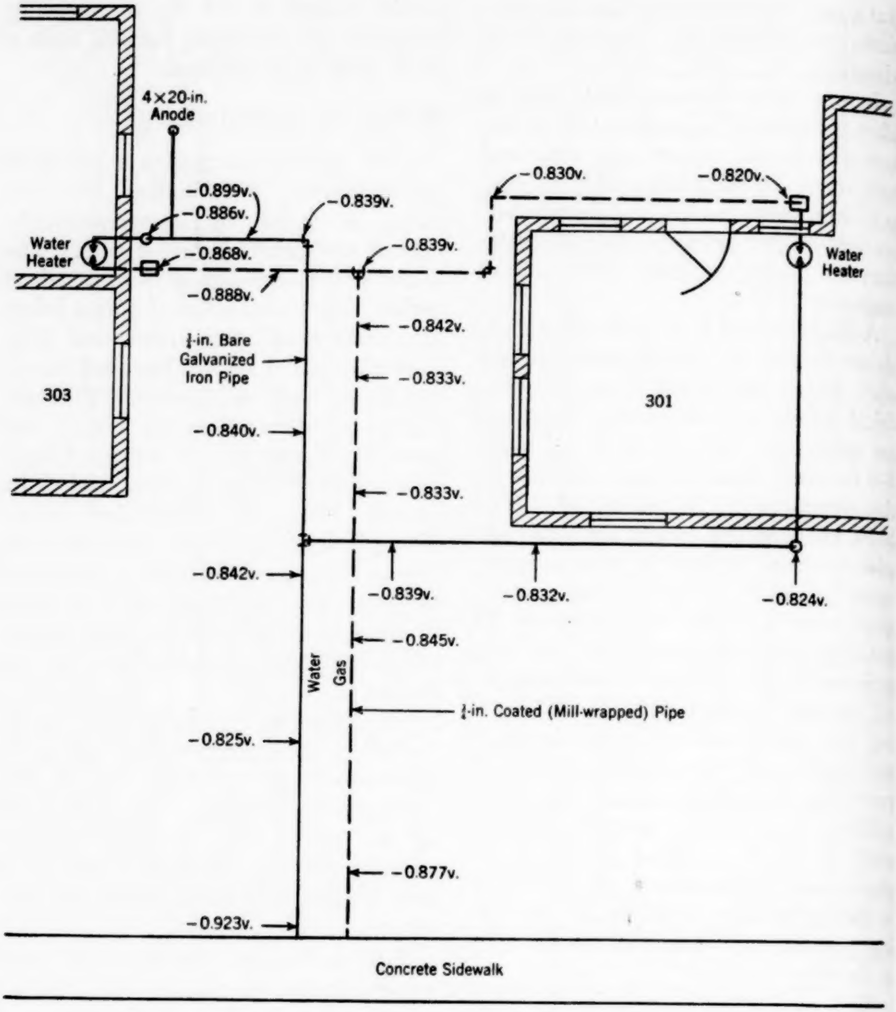

FIG. 3. Pipe-to-Soil Potential Distribution Adjacent to Anode

Since the calculations showed that one anode should be installed for every pair of houses, it was decided, for the sake of convenience, that this anode would be placed adjacent to the water meters on alternate houses. This would establish a consistent location for the anode throughout the entire town and also would permit an above-ground anode attachment at meter piping to facilitate any future testing.

The installation proper was carried out by the regular city water works maintenance crew of three men. Their equipment consisted of a 6-in. hand posthole auger, a shovel, a 55-gal. drum, an electric-driven portable agitator and a gasoline blowtorch solder-

ing outfit. Holes were augered to a depth of approximately 42 in. at a location about 10 ft. out from the meter piping. The 42-in. depth is satisfactory in places where the surface soil retains sufficient moisture throughout the year, but it is generally better to have the anode buried deeper, to be sure that it is in permanently moist soil.

While holes were being dug by one member of the crew, the other two prepared the backfill mixture. This was done by pouring 4.5 parts (by volume) of water, 1 part of gypsum and 3 parts of standard oil-field bentonite into the 55-gal. drum in the order listed, and then creaming the mixture to a thick but pourable slurry with the portable agitator. The slurry was then poured into the hole to a depth of approximately 30 in. A 4 × 20-in. cylindrical Dowmetal anode was next centered in the hole and pushed down into the slurry to within about 4 in. of the bottom. The remainder of the hole was then filled with topsoil. The preattached insulated anode wire was now trenched in to the meter, at which point it was soldered on the pipe. Each wire was spliced with a split-bolt type of connector to facilitate opening the circuit for test, and with that operation the installation was complete.

Performance

A pipe-to-soil potential and current-output survey made after all the anodes had been installed showed that within a week after the job was completed all the water and gas service lines in the area of the magnesium installation were under complete protection.

This potential and current survey, together with a potential survey prior to the application of the magnesium, are shown graphically for a typical section of the town in Fig. 2. Potential readings were made at the water meters with a $Cu \cdot CuSO_4$ electrode placed immediately adjacent to the pipe, and the value thus obtained was read with a Leeds and Northrup portable potentiometer. Current measurements were taken by reading the potential drop across a calibrated 0.01-ohm shunt temporarily inserted in the anode circuit.

The magnesium installation was completed in March 1946, and, as a check on its performance, potential and current surveys were made in October 1946 and May 1947. The results of these surveys for a typical section are also shown in Fig. 2. It is to be noted that after more than a year's operation the area has remained under protection.

The average current output per anode for the entire installation was 132 ma. in April 1946 and 84 in May 1947. The average pipe-to-soil potential (as measured at each meter) was − 0.681 v. before protection, − 0.910 in April 1946 and − 0.861 in May 1947. The somewhat lower values of current output and pipe-to-soil potential in the May 1947 survey are attributed to a long period of excessive dryness prior to the survey.

Field tests (3) have indicated that, under normal conditions, approximately 500 amp-hr. per pound of magnesium will be realized. On this basis, a 16-lb. anode—such as was used on this installation—draining at the rate of 180 ma., will have a five-year life and one draining at 90 ma., a ten-year life. The average life of this installation, then, will be from seven to ten years, assuming the anodes drain at some average rate intermediate to that

shown by the April 1946 and May 1947 surveys.

Figure 3 shows the pipe-to-soil potential distribution pattern on the piping around a typical pair of houses. The relative uniformity of the potentials indicates a uniform current distribution with no excess current going to the pipe immediately adjacent to the anode. It is to be noted that both gas and water piping show protection. As the mains are located under the street, it was not possible to determine whether they also are protected. The water mains may possibly not be completely protected because of the sectionalizing effect of the bell-and-spigot joints. It is reasonable to expect, however, that the gas mains are protected because of their electrical continuity and close proximity to the protected service lines.

Costs

Detailed cost records kept on the Lake Jackson project made it very evident, when compared with the costs of leak repairs, that the installation was justified. During the short, three-month interval in which leaks had been occurring, repair costs amounted to almost half the total cost of the cathodic protection installation. On this basis, the protection furnished will pay for itself many times over during the expected life of the installation.

Conclusions

From the experience obtained with this installation, it was found that magnesium possesses certain definite advantages over other types of cathodic protection for an application of this type. With the anodes spaced more or less equidistant along the structure, a very uniform current distribution was obtained on this installation, as shown by a pipe-to-soil potential distribution pattern for a typical pair of houses (Fig. 3). This type of installation operates at a considerably lower voltage and current output than would be required with the conventional single ground bed system—a factor which must be taken into account when studying the economics of a cathodic protection installation.

The driving voltage of magnesium is sufficient to assure a satisfactory current drain from the anode, and yet it is not high enough to cause injury to pipe coating. Experiments (4) have indicated that an applied potential in excess of 1.0 v. might injure bituminous pipe coatings. The maximum potential increase encountered in this installation did not exceed 0.3 v.

It is thought that the driving voltage is also low enough to prevent any serious "cathodic protection interference" with adjacent unprotected structures, such as is often encountered in complicated city distribution systems. "Cathodic protection interference" occurs when an unprotected structure gathers current from a near-by cathodic protection installation on one section and discharges it at another. At the point of discharge corrosion is accelerated. With the comparatively low driving potential of magnesium the tendency for current to be superimposed on an adjacent unprotected structure will be at a minimum.

Maintenance will be nil on this type of installation, where there are no moving parts, no external wiring or auxiliary power supply equipment. In addition, storms, fires and vandalism, which are common to all municipalities, can do no damage to this completely underground system. With

magnesium, there is no high voltage to present a hazard to personal safety.

In conclusion, it is to be pointed out that the outstanding performance of this installation has demonstrated that the corrosion of underground municipal lines can be definitely halted by the application of magnesium, that this type of protection is dependable and, finally, that the costs involved justify the installation of this form of cathodic protection.

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3. ———. Magnesium Anodes for the Cathodic Protection of Underground Structures. Corrosion, **2**:199 (Oct. 1946).
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Revision of Fire Service Type Meter Specifications

The Association's Board of Directors has approved a revision in the Tentative Standard Specifications for Cold Water Meters—Fire Service Type—7M.4–T. In the last sentence of Sec. 4–3.10.1—Mechanical Valves, *for:*

> Valve seats shall be of bronze, shall have the narrowest satisfactory width of face, shall be screwed into position and shall be equipped with sturdy lugs for easy removal.

read:

> Valve seats shall be of bronze, shall have a satisfactory width of face and shall be firmly held in place.

Flushometer Valve Problems in Temporary Shut-offs

By A. P. Bell and William H. Cary Jr.

A paper presented on Nov. 21, 1947, at the Four States Section Meeting, Washington, D.C., by A. P. Bell, Public Health Engr., and William H. Cary Jr., Director, Bureau of Public Health Eng., Dist. of Columbia Health Dept., Washington, D.C.

THE dangers and problems which may result from a temporary shut-off of water service were abundantly illustrated by an occurrence at a District of Columbia housing development in July 1947.

The development, situated on a 14-acre tract of land in the northwest section of the city, consists of three buildings containing 552 apartments, which range in size from one to fifteen rooms. Water service is furnished through an 8-in. connection to a 16-in. city water main located in the principal thoroughfare adjacent to the property. Each of the three buildings is equipped with centrifugal booster pumps and pressure tanks. The water pressure in the street main is 45 psi., and, under normal conditions, the pressure on the suction side of the pumps is 37 psi., which is boosted to 70 psi. The average consumption is about 0.97 mgd.

At 11 P.M. on July 24 the 16-in. city main was shut off while a new fire line was being installed. The control valve to the development was opened at 6:45 A.M. on July 25, and the valve crew was informed by the chief engineer of the development that satisfactory service had been resumed in the three buildings.

At approximately 8:15 A.M. the chief engineer called the Office of Operation and Maintenance of the Water Division and reported that he could not get sufficient water to his building pumps to supply the demands above the first floor. He stated that he thought the control valve had not been completely opened when it was operated. Thereupon the valve crew was immediately ordered to return to the scene. Its investigation indicated that the valve was open and that, because of the excessive use of water within the buildings, the capacity of the booster pumps was being exceeded. From past experience, the crew told the chief engineer it believed that the cause of the pressure failure was due to excessive loss of water through open flushometer valves.

Later in the day tests made at the four building meters showed a flow of approximately 2 mgd. passing through them, compared with the normal consumption of 0.97 mgd. When inspection by a Water Division official eliminated the possibility of a leak between the street main and the building valves, the theory of wastage through faulty fixtures within the building was corroborated.

A number of complaints were received from tenants early that evening by the Health Department. Public health engineers and the Water Super-

intendent arrived at the development at 7:30 P.M. A spot-check of the plumbing in the building indicated that serious back-siphonage hazards existed. Standard water-closet equipment consisted of rear-spud siphon-jet bowls equipped with flushometer valves not protected by backflow preventers. Two other facts were learned: first, no precautions had been taken to prevent back-siphonage at the time the water was shut off; second, the water supply was reported to be surging between the first and third floors in the risers in some of the buildings.

Emergency Measures

With this information at hand, a hurried conference was called in the building manager's office and, after a review of the significant facts, the tenants were notified in writing that they should boil all water to be used for drinking or culinary purposes until further notice. At the same time the Water Superintendent ordered an emergency crew to establish supplemental chlorination of the water supply coming into the development.

The boiling notice was mimeographed and distributed by the building management and reached the tenants at approximately 10:00 P.M. The emergency chlorinating crew was set up and operating at 10:15 P.M.

Fortunately, a permanent pitometer tap had been established in the 8-in. supply main to the project, which offered an ideal location for the injection of the 10 per cent sodium hypochlorite solution used in the chlorinating operations. A free chlorine residual in excess of 10 ppm. was being delivered throughout all portions of the buildings where water service was available, within a few minutes after the chlorinator went into service. This residual was maintained until midnight and then reduced to 2.5–5 ppm., where it was kept throughout the night and until 2:00 P.M. of July 26, four hours after water service had been restored to all parts of the buildings.

When it was definitely determined that the water wastage through flushometer valves was responsible for the lack of service in the buildings, immediate steps were taken to reestablish building pressures. Corrective procedures consisted of shutting off all risers or supply lines in order that the pumps might build up normal working pressures of 70 psi. in the hydraulic system. As soon as these pressures were obtained, one building riser at a time was placed in service. After restoring water service to a riser, it was necessary to visit all the apartments on it to determine whether or not the flushometer valves had seated properly and stopped flowing.

The work proceeded at a rather slow rate because of several complicating factors. There were a total of 790 flushometer valves to be checked and adjusted. The day crew of the building development had gone off duty leaving only two employees to accomplish the task. By the time this work was progressing with any regularity, many of the occupants were asleep and admittance was difficult. The shut-off had extended into the end of the week when many residents were away from home and their apartments, even though vacant, were double-locked, so that the management could not obtain entrance. In spite of these difficulties, complete service was restored in all buildings by approximately 10:00 A.M. on July 26, or 36 hours after the original interruption.

The Health Department collected four water samples at approximately

10:15 P.M. on July 25. Only one of these samples was obtained before chlorination. Seven water samples were collected on the morning of July 26 and four additional samples on July 27, approximately 18 hours after cessation of chlorination. Laboratory results showed all the samples to be negative for the coliform group with 24-hour plate counts of four or fewer colonies per milliliter. The boiling order was rescinded on Monday, July 28, after preliminary bacterial results indicating satisfactory conditions in the supply on Sunday, July 27, were available.

Flushometer Valve Difficulties

The major contributing factor to the shut-off problem is a commonly used plumbing device, the flushometer valve. Difficulties and failures associated with this valve are well known, and the Water Division reports that it has had similar experiences prior and subsequent to the incident described in this paper.

Flushometer valves can be divided into two types—diaphragm and piston—according to the method employed to control the flow of water. Both of these are sometimes further subdivided on the basis of whether or not the valve can be considered stable when subjected to a partial vacuum. Particulate material, wear or corrosion may cause a "stable" valve to develop unstable characteristics. The Bureau of Standards defines a stable type of flushometer valve as one that will remain closed in the absence of water pressure and in which the main valve will not open when a partial vacuum is applied to the supply line. Such a device must have an auxiliary valve so designed that it will allow air and water to pass through the piston or diaphragm to reduce any partial vacuum which may have developed in the upper chamber of the valve. Stable valves are more desirable because they tend to remain in a closed position and thus protect the public water supply from contamination through backsiphonage. Their ability to remain closed in the absence of water pressure also permits the restoration of water service without excessive mechanical adjustment.

With either type of valve, stable or unstable, 5–10 psi. of water pressure is necessary to reseat the valve after it has been opened. In fact, in some tests at the Bureau of Standards, pressures in excess of 10 psi. were required to close the valve after it had been tripped. All unstable valves, and, in some instances, stable valves as well, will open widely when a partial vacuum is substituted for positive pressure in the water supply line. Both the stable and unstable types will remain open if the valve is tripped during a period of low water pressure. Valves thus opened will not reseat themselves unless approximately 5–10 psi. of water pressure is available on the inlet side.

Aside from the low pressure due to the excessive loss of water through open flush valves, the restoration of service in the incident under discussion was delayed by the presence of a considerable amount of particulate material carried by the water. The shutoff in the street main, the reversal of flow in the building system and the greatly increased demand tended to agitate and break up loose sediment and corroded surfaces in the system. The resulting particles lodged in the working parts of many of the flushometer valves, requiring that they be

completely dismantled before normal operating conditions could be restored.

The public health aspect of this incident indicates the need for the closest cooperation between health and water departments. Fortunately, no serious illness resulted in this case. The buildings were occupied by a large number of government officials and congressmen and the repercussions could have assumed considerable magnitude.

Conclusions and Recommendations

This experience also brings out several other points that should not go unmentioned:

1. Large developments, particularly housing projects, should, whenever possible, have more than one water service. The fact that this development, and many others, are dependent upon one service connection and one street main for their source of water supply may at any time create a considerable health problem.

2. Although there were no reported cases of water-borne disease, it is significant that a large number of plumbing hazards existed in the buildings. It is important for health and plumbing inspection officials to extend their efforts to obtain the correction of such defects.

3. If all of the flush valves on the first floor of this housing development were flushed simultaneously, it would be impossible to draw any water on the upper floors or to restore service. Although the flush valves represent a major use of water, they are by no means the only fixtures available in the apartments. One wonders how many times partial vacuums have occurred on a riser, or in the entire upper portion of a building for that matter, because of the excessive use of water on the lower floors. The installation of service lines of sufficient size to meet peak demands is important. Regulatory agencies should be cautious in approving plans for large establishments of this nature, in order to insure against the hazards of back-siphonage in plumbing resulting from an inadequate supply of water.

4. The important role played by the individual riser shut-off valves should be emphasized. Without these valves, the task of reestablishing water service to all floors of the development would have been immeasurably more difficult. It is recommended that in the future, when plumbing codes are drafted or revised, provisions be included requiring valves at the lowest point of all service risers.

5. The need for wholehearted cooperation on the part of all interested parties cannot be overstressed. Although the probable cause of the difficulties was suggested by the valve crew on its return to the development shortly after the city water service had been restored, this explanation was not accepted or investigated until early in the evening, or approximately ten hours later. The fact that the Water Department did not have the right of entry to investigate the situation may have significance in this aspect of the incident.

6. It may be found desirable to have stand-by portable booster pumps available for the purpose of supplying sufficient quantities of water at high pressure to reestablish normal operating conditions in buildings where large numbers of flushometer valves are now in use. Under any circumstances, adequate planning to meet such an emergency should be made in advance.

In view of the difficulties experienced with multiple flushometer in-

stallations, it is recommended that water works, health and plumbing officials investigate this matter in greater detail. It would appear that the outlawing of the use of unstable flushometer valves might be a step in the right direction, though it does not necessarily follow that the use of the stable type now on the market would be a full solution to the problem. Certainly, the interruption of water service to large building units should not be undertaken unless ample precautions have been outlined for the protection of the health of those living or working on the premises.

Discussion

Thomas L. Amiss

Supt.-Engr., Dept. of Water and Sewerage, Shreveport, La.

Another instance of flushometer valve failure due to low pressure occurred recently at Barksdale Airfield, near Shreveport, La. Water for a population of over 5,000 is supplied directly to the field by a 12-in. line from a 20-in. main three miles away. The average rate of consumption during the month in which the accident took place was 716 gpm. The measured rate was 1,042 gpm., with a residual pressure before the meter of 25 psi. The pressure in the base, or operating center, was 16 psi. Floating on the system is a 500,000-gal. elevated steel tank at the entrance of the supply, so arranged that pumps can lift the water to the tank in the event of low pressure in the city system. There is also a 400,000-gal.-capacity standpipe 110 ft. high.

The trouble came about because the operators at the field allowed the reserve supply to be depleted to a point at which there was insufficient pressure to close a flushometer valve when it was operated. Normal water use, together with the failure of a number of flushometer valves, soon made the pressure too low to operate the service.

The writer was called in to investigate the difficulty. Since the water was entering the system as indicated by the meter, and no source of waste could be located, a large portion of the system was ordered closed down, cutting off many of the flushometers, and other water uses were also curtailed. As a result, the pressure began to increase, and, within a short time after it reached 30–40 psi., the system was again working normally. That night the reserves were filled and no trouble has since been encountered.

From this experience, the writer concludes that whenever the pressure drops below 25–30 psi., it cannot be rebuilt until the loss through the flushometers is overcome. This can be done by reinforcement, blocking off the system, reducing the waste or cutting off individual supplies in order to increase the pressure to 30–40 psi.

Analysis of Water-borne Outbreaks, 1938-45

By Rolf Eliassen and Robert H. Cummings

A contribution to the Journal by Rolf Eliassen, Prof. of San. Eng., and Robert H. Cummings, Instructor of San. Eng., both of the College of Eng., New York Univ., New York.

THE ultimate yardstick by which the services of the water works profession may be measured is the degree of control achieved over the outbreak of water-borne diseases. *Unfortunately, this control is seldom publicized in a positive manner, such as the number of consumer-days without a serious outbreak. If presented in this fashion, the score of the water works personnel would be 99.99 + per cent successful.* Instead, it is almost always the failures which appear in blazing headlines or in long epidemiological records that show only the occurrence of outbreaks when something has gone wrong, but hardly ever applaud when things go right.

Even though the over-all record of performance is good, the data on outbreaks should be of assistance to the water works profession if they are analyzed in terms of what can be done, in the design and operation of water works, to prevent their recurrence. An analysis of this type was presented by Gorman and Wolman (1) in 1939, based on recorded outbreaks from 1920 through 1936.

Further data, covering the years 1938 through 1945, have recently been made available in a voluminous report published as a Senate document (2). The data on water-borne outbreaks for these years were accumulated by the U.S. Public Health Service and presented by Thomas Parran, former U.S. Surgeon General, at a hearing before a subcommittee of the Senate Committee on Public Works, in connection with a proposed water pollution control bill. The apparent reason for introducing the data was to strengthen the evidence in favor of federal control of stream pollution by showing the incidence of water-borne disease outbreaks. No detailed analysis of the data was presented, however. Before any conclusions concerning the effect of stream pollution, or any other factors, on water-borne outbreaks can be drawn, it is necessary that a statistical breakdown of the data be made. Such a breakdown would also be of inestimable value in analyzing the problems of the water works profession from the public health standpoint and in measuring the success of its achievements.

The authors have prepared a statistical breakdown of the data for the years 1938 through 1945. No attempt has been made to duplicate the 147-page presentation of Gorman and Wolman (1) because the basic data are available in the Senate document (2). The objective has rather been to prepare a concise analysis of the U.S. Public Health Service data. Distinctions have been drawn between outbreaks attributable to water consumption from public utilities systems and from private supplies such as hotels,

TABLE 1

Water-borne Outbreaks in the U.S., 1938–45 (Classified by States)

State	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
Alabama			1	10,000	1	4	2	10,004
Arizona							0	0
Arkansas					1	63	1	63
California	2	13	1	200	3	10	6	223
Colorado							0	0
Connecticut			1	123	1	4	2	127
Delaware							0	0
Florida							0	0
Georgia	1	79	1	35	1	81	2*	195
Idaho							0	0
Illinois	3	418	1	195	2	73	6	686
Indiana	7	2,911	7	622	8	107	22	3,640
Iowa							0	0
Kansas	1	2,690			1	4	2	2,694
Kentucky	1	4	8	5,835	3	140	11*	5,979
Louisiana			2	275	3	24	5	299
Maine					1	2	1	2
Maryland	1	663	4	441	5	50	10	1,154
Massachusetts			8	338	2	8	10	346
Michigan	2	728					2	728
Minnesota			6	863	3	19	8*	882
Mississippi							0	0
Missouri			1	40	3	47	4	87
Montana							0	0
Nebraska							0	0
Nevada					1	6	1	6
New Hampshire							0	0
New Jersey			2	772	2	22	4	794
New Mexico	1	8	2	171	3	14	6	193
New York	7	554	132	44,106	13	87	151*	44,747
North Carolina			3	590	2	16	5	606
North Dakota					1	7	1	7
Ohio			2	2,500	11	53	13	2,553
Oklahoma			1	37	2	10	3	47
Oregon			2	1,254			2	1,254
Pennsylvania	3	273	2	113	2	37	7	423
Rhode Island							0	0
South Carolina					3	86	3	86
South Dakota							0	0
Tennessee					1	100	1	100
Texas	3	174	3	1,099	5	24	10*	1,297
Utah			1	117			1	117
Vermont							0	0
Virginia	2	94	4	360	5	116	11	570
Washington			2	2,003	1	6	3	2,009
West Virginia					4	42	4	42
Wisconsin	1	13	1	29,250			2	29,263
Wyoming					1	8	1	8
Washington, D.C.					1	8	1	8
Puerto Rico					3	81	3	81
TOTAL	35	8,622	198	101,339	99	1,359	327	111,320

* Outbreak of more than one disease at the same time and place.

summer camps, institutions and the like. Particular attention has been paid to the cause of the outbreaks where it was traced to a specific part of the water system.

It must first be emphasized that the accuracy of epidemiological data of this nature depends upon the system of reporting established in each state. Generally, cases of gastro-enteritis are not reported to health authorities. It follows that a higher incidence in any state may be attributed to a more accurate system of reporting, as well as to actual conditions.

General Statement

Before discussing in detail the tables included in this paper, it might be well to outline briefly the general picture presented by the data.

1. The record of the water works industry is exceedingly fine when measured in terms of the number of cases of water-borne disease among the more than 80,000,000 consumers of public water supplies.

2. In spite of the high state of the art of water treatment, outbreaks still occur, as evidenced by the 327 outbreaks resulting in 111,320 cases of water-borne disease from 1938 through 1945.

3. None of the outbreaks could be attributed to the inherent inability of a properly designed water treatment plant to handle the pollutional load placed on it. Rather, the failure of the human element to make the plant perform as it was capable of doing was responsible for many outbreaks.

4. Inadequate control of filtration or chlorination processes was considered to be responsible for a high percentage of the cases of water-borne disease. Stricter supervision of operation and more diligent performance of duties by the plant operators involved could have prevented these outbreaks.

5. Distribution system contamination through cross-connections and back-siphonage was responsible for 42 per cent of the number of cases of disease attributable to public water supplies. Similar outbreaks in other cities can only be avoided by thorough surveys of distribution systems and rigorous enforcement of cross-connection laws and regulations.

6. Private water supplies were responsible for 70 per cent of the total number of outbreaks in the country from 1938 through 1945. The use of ground water supplies without disinfection was the cause of more than half of these outbreaks. Education of the managers, builders and operators of the private water systems at camps, resort hotels and institutions is necessary to assure better safeguards against the consumption of contaminated water.

7. Supervision and control of private water supplies serving populations of 100 or more should be exercised by county health authorities or regional sanitary engineers of state health departments, backed by adequate legislation, to assure the provision of safe water to consumers of private supplies.

8. Disinfection should be mandatory for surface and ground water supplies in all water systems, whether public or private, serving groups of people above some arbitrary population figure, such as 100.

9. When measured in terms of consumer-days free from disease outbreak during 1938–45, public water supplies have been made safe throughout the country—regardless of contamination of the source—in all but an infinitesimally small number of cases found among the more than 80,000,000 consumers of those supplies. Improvements in the record of disease-free consumer-days can and must be made by the application of technological ad-

TABLE 2

*Water-borne Outbreaks in the U.S., 1938–45 * (New York State Separate)*

Year	Location	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
		Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
1938	New York State	4	394	16	463	4	37	24	894
	All others	4	985	6	29,645	14	169	23†	30,799
	Total	8	1,379	22	30,108	18	206	47	31,693
1939	New York State			21	935			21	935
	All others	3	265	6	957	13	97	21†	1,319
	Total	3	265	27	1,892	12	97	42	2,254
1940	New York State	1	110	19	36,594	1	6	20†	36,710
	All others	4	2,577	8	4,482	10	165	22	7,224
	Total	5	2,687	27	41,076	11	171	42	43,934
1941	New York State	2	50	14	354	1	5	17	409
	All others	9	198	13	11,182	21	247	43	11,627
	Total	11	248	27	11,536	22	252	60	12,036
1942	New York State			25	3,183	3	17	28	3,200
	All others	7	4,039	13	3,850	6	197	25†	8,086
	Total	7	4,039	38	7,033	9	214	53	11,286
1943‡	New York State			6	391			6	391
	All others			9	4,951	11	220	19†	5,171
	Total			15	5,342	11	220	25	5,562
1944§	New York State			17	760	2	11	19	771
	All others	1	4	8	1,842	4	19	13	1,865
	Total	1	4	25	2,602	6	30	32	2,636
1945‖	New York State			14	1,426	2	11	16	1,437
	All others			3	324	7	158	10	482
	Total			17	1,750	9	169	26	1,919
1938–1945	New York State	7	554	132	44,106	13	87	151	44,747
	All others	28	8,068	66	57,233	86	1,272	176	66,573
	Total	35	8,622	198	101,339	99	1,359	327	111,320

* Totals include reports from all states, the District of Columbia and Puerto Rico.
† Outbreak of more than one disease at the same time and place.
‡ No reports from Arizona, Louisiana and Minnesota.
§ No reports from Mississippi, Missouri, Pennsylvania and Utah.
‖ No reports from Colorado and Pennsylvania.

vances and the continued faithful performance of their duties by the men of the water works industry and allied professions.

10. During the war years 1941–45, when water systems were taxed beyond normal capacities and personnel problems were acute, the number of cases of water-borne diseases reported was less than for the preceding years 1938–40. Safe water has been, and will continue to be, provided by the water works industry.

Geographic Distribution

A summary of the total number of outbreaks and cases reported for 1938 through 1945 is presented in Table 1. The breakdown has been made according to states and to three categories of infection involved: bacillary dysentery, gastro-enteritis and typhoid fever. This table represents a total of 111,320 cases of disease attributable to water-borne infection for the eight years reported.

Casual analysis of Table 1 reveals that in some outbreaks large numbers of cases were involved, with the result that certain states—particularly Alabama, New York and Wisconsin—contributed almost 80 per cent of the cases. A description of those outbreaks affecting large numbers of people will be presented later in this paper in connection with analysis of the specific causes.

As a matter of interest, Table 2 has been prepared to show the occurrence of outbreaks for each year from 1938 through 1945. The data have been separated to indicate the relationship between reports from New York State and the total of the other 47 states in relation to the total for each year from all of the states.

It will be noted that the large number of cases in New York State is associated with a proportionately large number of outbreaks. The 151 outbreaks reported in the state over the eight-year period represent 46 per cent of the total outbreaks reported for the whole country and 40 per cent of the total cases. However, the total number of cases includes one outbreak in Rochester, N.Y., where approximately 35,000 persons were stricken with gastro-enteritis. Excluding this one large outbreak, New York State had a total of 150 outbreaks with a total of 10,000 cases, or an average of 66 cases per outbreak. This indicates many comparatively small outbreaks, such as those reported from summer camps and small resort hotels.

This intensity of reporting reflects the close control which the New York State Dept. of Health exercises over its resort areas, particularly in the congested districts of the Catskill Mountains. A special staff of sanitary engineers and inspectors patrols this and other areas each summer season, with the result that all minor outbreaks are reported and attempts made to correct the deficiencies. It seems fair to assume that if other states exerted similar care in their congested recreational areas, the record of outbreaks and cases attributable to small private water supplies might be much higher.

Points of Pollution

The point at which pollution entered the system, or at which the disinfection of pollution failed of accomplishment, is of primary importance to the water works operator. A study of the data published in the Senate document (2) reveals that contamination in the distribution system was the cause of the greatest number of cases of water-borne

TABLE 3

Total Water-borne Outbreaks in the U. S., 1938–45
(Classified by Point of Pollution in Water System)

Point of Pollution	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
All reported outbreaks								
Untreated surface water	1	16	20	892	23	313	44	1,221
Untreated ground water	15	1,348	94	6,358	52	761	159*	8,467
Contamination of reservoirs or cisterns			2	114	1	4	3	118
Inadequate control over water purification	6	2,975	30	18,141	3	123	38*	21,239
Contamination in distribution system	4	3,250	30	43,491	3	30	36*	46,771
Contamination in collection or conduit system			3	520	1	7	4	527
Miscellaneous	9	1,033	19	31,823	16	121	43*	32,977
Total	35	8,622	198	101,339	99	1,359	327	111,320
Public water supplies only								
Untreated surface water			5	339	10	233	15	572
Untreated ground water	3	821	13	2,796	10	282	25*	3,899
Contamination of reservoirs or cisterns							0	0
Inadequate control over water purification	5	2,894	14	17,114	1	106	19*	20,114
Contamination in distribution system	3	3,000	18	40,556	3	30	23*	43,586
Contamination in collection or conduit system			2	250			2	250
Miscellaneous	6	729	6	30,881	5	54	16*	31,664
Total	17	7,444	58	91,936	29	705	100	100,085
Private water supplies only								
Untreated surface water	1	16	15	553	13	80	29	649
Untreated ground water	12	527	81	3,562	42	479	134*	4,568
Contamination of reservoirs or cisterns			2	114	1	4	3	118
Inadequate control over water purification	1	81	16	1,027	2	17	19	1,125
Contamination in distribution system	1	250	12	2,935			13	3,185
Contamination in collection or conduit system			1	270	1	7	2	277
Miscellaneous	3	304	13	942	11	67	27	1,313
Total	18	1,178	140	9,403	70	654	227	11,235

* Outbreak of more than one disease at the same time and place.

TABLE 4

Per Cent of Water-borne Outbreaks in the U.S., 1938–45
(Classified by Point of Pollution in Water System)

Point of Pollution	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
	per cent							
All reported outbreaks								
Untreated surface water	2.8	0.2	10.1	0.9	23.3	23.0	13.5	1.1
Untreated ground water	43.0	15.6	47.4	6.3	52.5	56.0	48.7	7.6
Contamination of reservoirs or cisterns			1.9	0.1	1.0	0.3	0.9	0.1
Inadequate control over water purification	17.1	34.5	15.2	17.9	3.0	9.1	11.6	19.1
Contamination in distribution system	11.4	37.7	15.2	42.9	3.0	2.2	11.0	42.0
Contamination in collection or conduit system			1.5	0.5	1.0	0.5	1.2	0.5
Miscellaneous	25.7	12.0	9.6	31.4	16.2	8.9	13.1	29.6
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Public water supplies only								
Untreated surface water			2.5	0.3	10.1	17.1	4.6	0.5
Untreated ground water	8.6	9.5	6.5	2.8	10.1	20.8	7.7	3.5
Contamination of reservoirs or cisterns							0.0	0.0
Inadequate control over water purification	14.3	33.5	7.1	16.9	1.0	7.8	5.8	18.1
Contamination in distribution system	8.6	34.8	9.1	40.0	3.0	2.2	7.0	39.2
Contamination in collection or conduit system			1.0	0.2			0.6	0.2
Miscellaneous	17.1	8.5	3.1	30.5	5.1	4.0	4.9	28.4
TOTAL	48.6	86.3	29.3	90.7	29.3	51.9	30.6	89.9
Private water supplies only								
Untreated surface water	2.8	0.2	7.6	0.6	13.2	5.9	8.9	0.6
Untreated ground water	34.4	6.1	40.9	3.5	42.4	35.2	41.0	4.1
Contamination of reservoirs or cisterns			1.0	0.1	1.0	0.3	0.9	0.1
Inadequate control over water purification	2.8	1.0	8.1	1.0	2.0	1.3	5.8	1.0
Contamination in distribution system	2.8	2.9	6.1	2.9			4.0	2.8
Contamination in collection or conduit system			0.5	0.3	1.0	0.5	0.6	0.3
Miscellaneous	8.6	3.5	6.5	0.9	11.1	4.9	8.2	1.2
TOTAL	51.4	13.7	70.7	9.3	70.7	48.1	69.4	10.1

TABLE 5

Water-borne Outbreaks in the U. S., 1938–45—Public Water Supplies (Classified by Causes)

Classification	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
Surface water supplies (untreated)								
Contamination of brook or stream by pollution on watershed			3	284	3	62	6	346
Use of polluted water from river or irrigation ditch—untreated			1	43	3	12	4	55
Contamination of spring or infiltration gallery by pollution on watershed					1	49	1	49
Contamination of spring or infiltration gallery by flood waters					1	63	1	63
Contamination of spring by adjacent sewer or sewage tank					2	47	2	47
Contamination of spring by surface pollution			1	12			1	12
TOTAL			5	339	10	233	15	572
Underground water supplies (untreated)								
Contamination of spring through creviced limestone or fissured rock			1	200			1	200
Contamination of spring—source unknown					2	45	2	45
Contamination of well by adjacent sewer or sewage tank					3	130	3	130
Contamination of well from adjacent river or lake			1	75			1	75
Faulty well casing or construction			3	106			3	106
Overflow of sewer or flood into top of well casing			2	1,300			2	1,300
Surface contamination of well	2	742			2	12	4	754
Contamination of well through creviced limestone or fissured rock	1	79	1	60	1	81	2*	220
Contamination of well by surface pollution through abandoned well					1	11	1	11
Contamination of well—source unknown			5	1,055	1	3	6	1,058
TOTAL	3	821	13	2,796	10	282	25	3,899
Water purification								
Inadequate control of filtration and allied treatment	2	2,560	3	10,265			5	12,825
Inadequate chlorination—only treatment	1	100	7	1,523			8	1,623
Inadequate chlorination—other treatment			3	5,266	1	106	3*	5,372
Interruption of chlorination—only treatment	1	84	1	60			2	144
New equipment not properly disinfected	1	150					1	150
TOTAL	5	2,894	14	17,114	1	106	19	20,114

TABLE 5—*Continued*

Classification	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
Reservoir or cistern storage							0	0
Distribution system								
Pollution of water mains during construction or repairs			3	791			3	791
Cross-connection with polluted water supply	3	3,000	6	38,534	1	6	9*	41,540
Back-siphonage of polluted water			5	804	1	14	6	818
Break in mains permitting sewage or river water to enter			2	290	1	10	3	300
New paint in water tank			2	137			2	137
TOTAL	3	3,000	18	40,556	3	30	23	43,586
Collection or conduit system								
Auxiliary intake to polluted source			2	250			2	250
TOTAL			2	250			2	250
Miscellaneous								
Use of polluted private supply because of objectionable taste or quality of public supply	1	20			2	11	2*	31
Use of polluted water not intended for drinking purposes					1	17	1	17
Data insufficient for classification	5	709	6	30,881	2	26	13	31,616
TOTAL	6	729	6	30,881	5	54	16	31,664
GRAND TOTAL	17	7,444	58	91,936	29	705	100	100,085

* Outbreak of more than one disease at the same time and place.

disease among consumers of public water supplies. Although this same cause also affected many individuals using private supplies, the greatest number of cases among these consumers was the use of untreated ground water.

A statistical summary of the number of outbreaks and cases of bacillary dysentery, gastro-enteritis and typhoid fever for public and private water supplies is presented in Table 3. A breakdown into points of pollution in the water system was made for each of the disease types and for public and private supplies. This breakdown utilizes a classification similar to that employed in Table 9-A of the Gorman-Wolman report (1) and will facilitate comparisons with past data by the interested reader.

To achieve a more definitive analysis of the data in Table 3, a further breakdown was made on a percentage basis. Table 4 was prepared using the total number of cases and outbreaks for each disease category as the 100 per cent level. This permits a more rapid evalu-

ation of the significance of each point of pollution as the cause of each type of disease. It is evident that inadequate control over water purification and contamination in the distribution system were responsible for the greatest percentage of cases of dysentery and gastro-enteritis. On the other hand, untreated surface and ground water supplies resulted in the largest percentage of typhoid fever outbreaks. The outbreak of any water-borne disease is a serious black mark against a water system, but it is evident from the data that many points in the system have been responsible for outbreaks.

In order to compare the relative responsibilities of public and private water supplies * for the outbreak of disease, the results of Table 4 were subjected to graphical analysis in Fig. 1 and 2, which present respectively a comparison of outbreaks and of cases

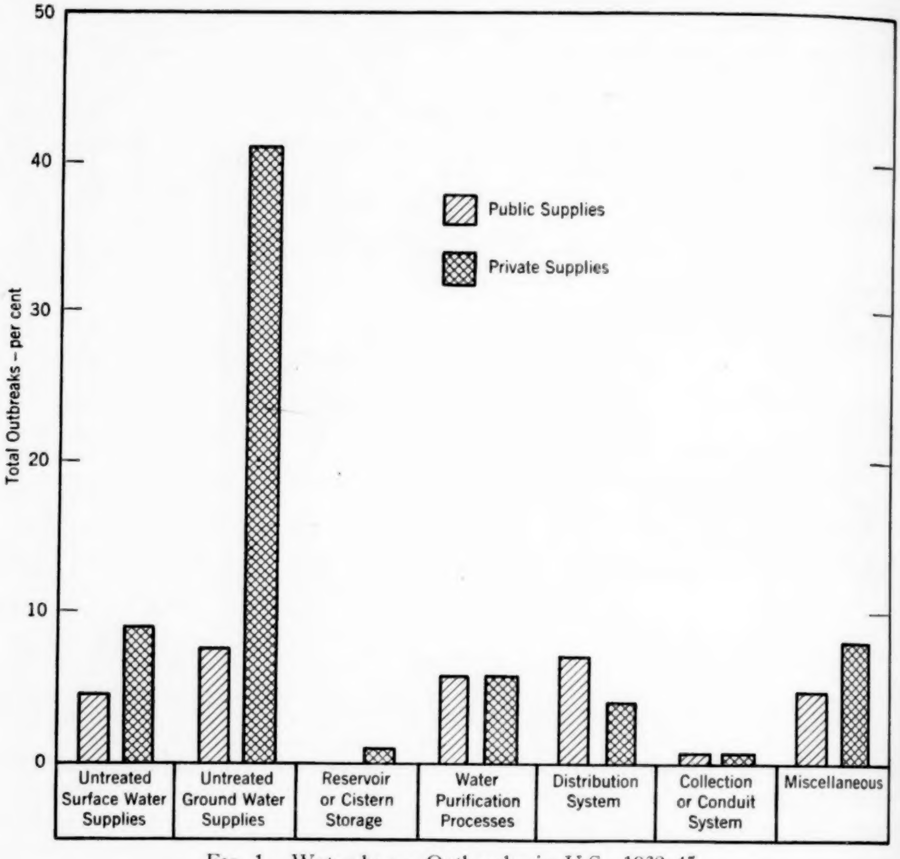

FIG. 1. Water-borne Outbreaks in U.S., 1938–45
(Classified as to Point of Pollution)

* The terms "public" and "private" as used in this paper refer not to the ownership of the utility but to the type of service it renders. Generally, public supplies are municipal supplies, made available, as any public utility would be, to all those within a certain area. Private supplies are those provided for guests at hotels, resorts, summer camps, etc.; the term also includes industry-owned supplies used by workers for potable purposes.

according to the point of pollution. The total number of outbreaks and the total number of cases serve as the 100 per cent bases respectively.

Private water supplies utilizing untreated ground water accounted for 41 per cent of the total outbreaks for 1938 through 1945. Untreated surface water added another 8.9 per cent. These two categories of private supplies therefore accounted for half the outbreaks throughout the whole country. It is evident why states such as New York must exercise vigilance in the inspection and improvement of water supplies for summer camps, resorts, hotels, institutions and other private places not served by public water supplies.

Public water supplies accounted for only 30 per cent of the total number of outbreaks in spite of the fact that an extremely large population, estimated at about 80,000,000 people,* is served throughout each day of the year by these supplies. However, 90 per cent of the total number of cases were caused by the consumption of public water supplies. Of these cases, almost half were attributable to contamination in the distribution system. Only 0.5 per cent were caused by the use of untreated surface water and 3.5 per cent by untreated ground water.

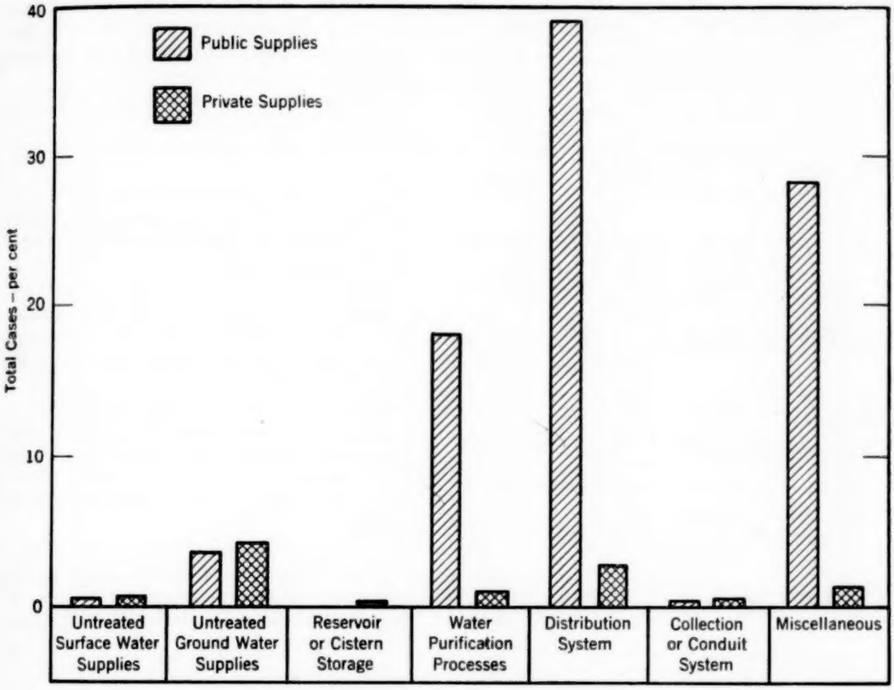

FIG. 2. Number of Cases in Water-borne Outbreaks, 1938–45
(Classified as to Point of Pollution)

With so much attention being focused in the newspapers and magazines of late on the gross pollution of streams and

* This figure is considered valid for 1938, at the beginning of the eight-year period covered by this study. It is estimated that urban growth adds 500,000 to the number each year.

TABLE 6

Water-borne Outbreaks in the U.S., 1938–45
(Involving 500 Cases or More)

Year	Location	No. of Cases	Disease	Remarks
1938	Bel Air, Md.	663	Dysentery	Insufficient data for classification; public water supply.
	Milwaukee, Wis.	29,250	Gastro-enteritis	Insufficient data for classification; public water supply. Gorman and Wolman (1) state: "There is strong presumptive evidence that contaminated water, not treated with sufficient chlorine, may have been the cause. . . ." A full report was published by the Wisconsin State Board of Health (3).
1939	none			
1940	Seymour, Ind.	2,250	Dysentery	Filtration plant not operated properly, as evidenced by great amount of turbidity in finished water.
	Georgetown, Ky.	2,100	Gastro-enteritis	Operation of filtration plant unsatisfactory. It is believed that the chlorinator broke down and for some days water was not chlorinated.
	Henderson, Ky.	2,000–2,500	Gastro-enteritis	Due to friction among employees, some employees reduced the chlorine doses below that recommended by the State Health Dept. in order to gain credit for economizing.
	Rochester, N.Y.	35,000 6	Gastro-enteritis Typhoid Fever	Cross-connection between polluted fire protection system and potable water. An employee accidentally left a valve between the two systems open.
1941	Gadsden, Ala.	10,000	Gastro-enteritis	Faulty operation of the water treatment plant. The regular superintendent had been away sick for some length of time. Gorman and Wolman (1) report that 35 cases of typhoid fever were water-borne in 1920 in Gadsden. The 1920 outbreak was due to faulty operation of the water treatment plant while the regular superintendent was away on vacation.
	Navarre, Ohio	500	Gastro-enteritis	Contamination of public well; source unknown.

TABLE 6—*Continued*

Year	Location	No. of Cases	Disease	Remarks
1942	Newton, Kan.	2,690	Dysentery	Cross-connection of public potable supply with sewer system.
	Seneca County, N.Y.	1,000	Gastro-enteritis	Insufficient data for classification; public water supply.
	Sidney, N.Y.	2,329* 348†	Gastro-enteritis	Public water supply; inadequate chlorination the only treatment.
	St. Marys, Ohio	2,000	Gastro-enteritis	Municipal supply contaminated with polluted canal water through failure of check valves on cross-connection with fire-fighting system.
1943	Harrodsburg, Ky.	1,166 106	Gastro-enteritis Typhoid Fever	Auxiliary public supply from deep wells inadequately chlorinated.
	Elkton, Md.	‡	Gastro-enteritis	Population of town 3,518 (1940 census); 5,000 individuals exposed to suspected vehicle of contamination. Insufficient chlorination of public water supply due to breakdown of chlorinator.
	Portland, Ore.	1,179	Gastro-enteritis	Cross-connection in shipyard between polluted river water and municipal supply.
	Seattle, Wash.	1,911	Gastro-enteritis	The water supply system in a shipyard was cross-connected with untreated water from Lake Washington (fire-fighting supply).
1944	Bay City, Tex.	1,000	Gastro-enteritis	Contamination of public wells by flood.
	Forest City, N.C.	500	Gastro-enteritis	Back-siphonage of waste water into city storage tank.
1945	Ellenville, N.Y.	800	Gastro-enteritis	Chlorine residual in public water supply fell below required value.
	Geneva, N.Y.	4,000* 60†	Gastro-enteritis	The public water supply was chlorinated immediately at the pumping station where water entered the public mains. During the 20-minute periods that it took to change chlorine cylinders the pump was not shut off.

* Estimated. † Known. ‡ Numerous.

TABLE 7

Water-borne Outbreaks in the U. S., 1938–45—Private Water Supplies (Classified by Causes)

Classification	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
Surface water supplies (untreated)								
Contamination of brook or stream by pollution on watershed			1	100			1	100
Use of polluted water from river or irrigation ditch—untreated			10	390	4	16	14	406
Use of polluted lake water—untreated			2	29	2	12	4	41
Contamination of spring or infiltration gallery by flood waters					1	6	1	6
Contamination of spring by adjacent sewer or sewage tank					3	15	3	15
Contamination of spring by surface pollution	1	16	2	34	2	22	5	72
Faulty construction of spring					1	9	1	9
TOTAL	1	16	15	553	13	80	29	649
Underground water supplies (untreated)								
Contamination of spring through creviced limestone or fissured rock			1	129			1	129
Contamination of spring—source unknown	4	92	7	163	4	61	15	316
Contamination of spring and well—source unknown			4	181			4	181
Contamination of well by adjacent sewer or sewage tank	1	2	17	939	11	140	28*	1,081
Contamination of well from adjacent river or lake			1	75			1	75
Faulty well casing or construction	2	38	11	275	6	30	19	343
Overflow of sewer or flood into top of well casing	1	241	2	115	2	42	5	398
Surface contamination of well	1	20	7	248	10	87	18	355
Contamination of well through creviced limestone or fissured rock	2	24	4	237	1	2	7	263
Contamination of well by surface pollution through abandoned well			1	13			1	13
Contamination of well—source unknown	1	110	26	1,187	8	117	35	1,414
TOTAL	12	527	81	3,562	42	479	134	4,568
Reservoir or cistern storage								
Seepage from sewer or surface into cracked cistern or leak in water tank			1	13	1	4	2	17
New storage tank not disinfected properly			1	101			1	101
TOTAL			2	114	1	4	3	118

* Outbreak of more than one disease at the same time and place.

TABLE 7—*Continued*

Classification	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
Water purification								
Inadequate control of filtration and allied treatment	1	81	1	24	1	7	3	112
Inadequate chlorination—only treatment			8	718	1	10	9	728
Interruption of chlorination—only treatment			7	285			7	285
TOTAL	1	81	16	1,027	2	17	19	1,125
Distribution system								
Pollution of water mains during construction or repairs	1	250	3	354			4	604
Leaking water main and sewer in same trench			1	40			1	40
Cross-connection with polluted water supply			6	2,461			6	2,461
Back-siphonage of polluted water			2	80			2	80
TOTAL	1	250	12	2,935			13	3,185
Collection or conduit system								
Auxiliary intake to polluted source			1	270			1	270
Seepage of surface water or sewage into gravity conduit					1	7	1	7
TOTAL			1	270	1	7	2	277
Miscellaneous								
Use of polluted water not intended for drinking purposes			1	39			1	39
Cause of outbreak undetermined			2	179	1	3	3	182
Data insufficient for classification	3	304	5	300	10	64	18	668
Swimming in polluted water			1	35			1	35
Improper use of bottled water			2	57			2	57
Ice improperly handled			2	332			2	332
TOTAL	3	304	13	942	11	67	27	1,313
GRAND TOTAL	18	1,178	140	9,403	70	654	227	11,235

its effect on public health, it behooves the members of the water works profession to examine Fig. 1 and 2 to see if other matters besides stream pollution do not need their attention.

For the purpose of a more detailed study of the causes of water-borne diseases, a further breakdown of the data was made.

Causes of Pollution in Public Supplies

Table 5 shows the causes of the 100 reported outbreaks resulting in 100,085 cases of water-borne disease attributable to public water supplies during 1938 through 1945. Surface water supplies without treatment by disinfection or

other means accounted for only 15 outbreaks and 572 cases of disease. It is fortunate that more outbreaks did not occur when no chlorination was provided. Even the best-policed surface water supply may be subject to some form of contamination, and the slight cost of disinfection cannot be balanced against the gamble with public health.

Underground water supplies delivered to the consumer without treatment were responsible for 25 outbreaks with 3,899 cases. The nine causes indicated are evidence of the uncertainties involved in using ground water without disinfection. The present state of the art of water treatment makes it imperative that no compromise be tolerated on the part of municipal officials or utilities management when it comes to the disinfection of public water supplies.

A failure of water purification and treatment facilities is a direct reflection on the water works profession, which has undertaken the responsibility for the protection of public water supplies. Prominent among the causes for the 19 outbreaks and 20,114 cases of disease was inadequate control of filtration and allied treatment. This cause was responsible for 5 outbreaks resulting in 12,825 cases of water-borne disease, mostly gastro-enteritis. Inadequate or interrupted chlorination caused 13 outbreaks with 7,139 cases. Foresight is needed on the part of designing engineers and operating personnel to provide equipment with sufficient reserve capacity and to operate this equipment in such a manner that chlorination will never be inadequate. This is one of the prime responsibilities of the water works profession. It can only be carried to successful completion by continued vigilance and faithful service on the part of those to whom these duties are entrusted.

Table 5 emphasizes the significance of the distribution systems of public water supplies in the cause and prevention of water-borne diseases. It is immediately apparent that the long campaign of the water works profession for the adequate disinfection of water mains during construction and repair has borne fruit. Only three outbreaks, with 791 cases of gastro-enteritis, were reported as being caused by inadequate disinfection of mains before use. The fact that outbreaks can occur makes it advisable that present disinfection practices be continued and that new methods be developed so that the record may be improved in years to come.

Cross-connections of distribution systems with polluted water supplies and the back-siphonage of polluted water led to 15 outbreaks and 42,358 cases of disease. This represents 42 per cent of the total cases from all causes attributable to public water supplies. Much has been written in the technical literature about the need for cross-connection surveys. Active elimination programs have been carried out by many cities against the sources of cross-connections and points of potential back-siphonage. The need for further action is emphasized by these figures, which speak for themselves.

The other causes of disease outbreaks noted in Table 5 under "Miscellaneous" are difficult to evaluate without a more detailed consideration of the circumstances involved. Most of the 31,616 cases in this category were encountered in the 1938 outbreak at Milwaukee, Wis. The evidence obtained by the investigators was insufficient to determine the specific cause for this outbreak, as described in the report published by the Wisconsin State Board of Health (3). Gorman and Wolman, however, stated (1) that "there is

strong presumptive evidence that contaminated water, not treated with sufficient chlorine, may have been the cause." The need for better and more rapid coordination of epidemiological and engineering investigations is evident.

One single outbreak on a public water supply may lead to so many cases of disease that the case statistics may become heavily unbalanced when compared with the total number of outbreaks. Of the 100,000 cases reported in 100 outbreaks, three-quarters were encountered during only three outbreaks: at Milwaukee, Wis.; Rochester, N.Y.; and Gadsden, Ala.*

Other relatively large outbreaks, in which 500 or more cases of disease were estimated or reported, are outlined chronologically in Table 6.

The experiences in these large outbreaks serve to emphasize the points brought out in the previous discussion of Table 5. Insufficient chlorination, faulty operation and inadequate capacity of filtration plants, cross-connections and back-siphonage—all these have contributed to large outbreaks of water-borne disease. Most of these outbreaks could have been avoided by the application of known principles of sanitary engineering and through the diligent performance of their duties by water works employees and managers.

*It is highly important to note that both Milwaukee, Wis., and Gadsden, Ala., have constructed modern and efficient filtration plants since these outbreaks occurred. In Rochester, N.Y. (4), the practice of using untreated river water in the separate high-pressure fire-fighting system has been abandoned. This system, although separate in distribution from the regular public water supply, now uses the public supply as the source of the water delivered by it to the fire mains. In other words, the conditions which were responsible for the three major outbreaks have long been completely corrected, a fact which is to the credit of the water works industry.

Causes of Pollution in Private Supplies

The 227 outbreaks of disease among consumers of private water supplies are classified with respect to causes in Table 7. The total number of cases reported was 11,235, giving an average of 50 cases per outbreak. As opposed to this figure, the 100 outbreaks involving public water supplies averaged 1,000 cases per outbreak, a result influenced greatly by the large outbreaks previously noted. (Table 8 combines Tables 5 and 7, giving the totals for all water supplies.)

Untreated underground water supplies caused the largest number of outbreaks and individual cases among consumers of private water supplies. The specific causes noted in Table 7 are all familiar to water works personnel, particularly the known cause of the largest number of cases—the contamination of wells by adjacent sewers, septic tanks and drain fields.

Defects of distribution systems of private water supplies also contributed heavily to cases of disease. Cross-connections, back-siphonage and lack of disinfection of pipes during construction are all avoidable causes. Education of managers and owners of resort hotels, camps and institutions, as well as engineers, plumbers and architects who are engaged in the design and construction of private water systems, is one of the ways of decreasing the number of outbreaks.

Virtual elimination of the hazards associated with many private water supplies is only possible by more effective inspection and control by regulatory agencies. State health departments are generally not adequately

TABLE 8

Total Water-borne Outbreaks in the U. S., 1938–45 (Classified by Causes)

Classification	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
Surface water supplies (untreated)								
Contamination of brook or stream by pollution on watershed			4	384	3	62	7	446
Use of polluted water from river or irrigation ditch—untreated			11	433	7	28	18	461
Use of polluted lake water—untreated			2	29	2	12	4	41
Contamination of spring or infiltration gallery by pollution on watershed					1	49	1	49
Contamination of spring or infiltration gallery by flood waters					2	69	2	69
Contamination of spring by adjacent sewer or sewage tank					5	62	5	62
Contamination of spring by surface pollution	1	16	3	46	2	22	6	84
Faulty construction of spring					1	9	1	9
TOTAL	1	16	20	892	23	313	44	1,221
Underground water supplies (untreated)								
Contamination of spring through creviced limestone or fissured rock			2	329			2	329
Contamination of spring—source unknown	4	92	7	163	6	106	17	361
Contamination of spring and well—source unknown			4	181			4	181
Contamination of well by adjacent sewer or sewage tank	1	2	17	939	14	270	31*	1,211
Contamination of well from adjacent river or lake			2	150			2	150
Faulty well casing or construction	2	38	14	381	6	30	22	449
Overflow of sewer or flood water into top of well casing	1	241	4	1,415	2	42	7	1,698
Surface contamination of well	3	762	7	248	12	99	22	1,109
Contamination of well through creviced limestone or fissured rock	3	103	5	297	2	83	9*	483
Contamination of well by surface pollution through abandoned well			1	13	1	11	2	24
Contamination of well—source unknown	1	110	31	2,242	9	120	41	2,472
TOTAL	15	1,348	94	6,358	52	761	159	8,467
Reservoir or cistern storage								
Seepage from sewer or surface into cracked cistern or leak in water tank			1	13	1	4	2	17
New storage tank not disinfected properly			1	101			1	101
TOTAL			2	114	1	4	3	118

TABLE 8—*Continued*

Classification	Dysentery		Gastro-enteritis		Typhoid Fever		Total	
	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases	Out-breaks	Cases
Water purification								
Inadequate control of filtration and allied treatment	3	2,461	4	10,289	1	7	8	12,937
Inadequate chlorination—only treatment	1	100	15	2,241	1	10	17	2,351
Inadequate chlorination—other treatment			3	5,266	1	106	3*	5,372
Interruption of chlorination—only treatment	1	84	8	345			9	429
New equipment not properly disinfected	1	150					1	150
TOTAL	6	2,975	30	18,141	3	123	38	21,239
Distribution system								
Pollution of water mains during construction or repairs	1	250	6	1,145			7	1,395
Leaking water main and sewer in same trench			1	40			1	40
Cross-connection with polluted water supply	3	3,000	12	40,995	1	6	15*	44,001
Back-siphonage of polluted water			7	884	1	14	8	898
Break in mains permitting sewage or river water to enter			2	290	1	10	3	300
New paint in water tank			2	137			2	137
TOTAL	4	3,250	30	43,491	3	30	36	46,771
Collection or conduit system								
Auxiliary intake to polluted source			3	520			3	520
Seepage of surface water or sewage into gravity conduit					1	7	1	7
TOTAL			3	520	1	7	4	527
Miscellaneous								
Use of polluted private supply because of objectionable taste or quality of public supply	1	20			2	11	2*	31
Use of polluted water not intended for drinking purposes			1	39	1	17	2	56
Cause of outbreak undetermined			2	179	1	3	3	182
Data insufficient for classification	8	1,013	11	31,181	12	90	31	32,284
Swimming in polluted water			1	35			1	35
Improper use of bottled water			2	57			2	57
Ice improperly handled			2	332			2	332
TOTAL	9	1,033	19	31,823	16	121	43	32,977
GRAND TOTAL	35	8,622	198	101,339	99	1,359	327	111,320

* Outbreak of more than one disease at the same time and place.

staffed to supervise private water supplies serving groups as low as 100 in population. Furthermore, control on the state level may be too remote, considering the type of personnel frequently employed to operate these private supplies.

The most encouraging development of late years is the growth of county health units. Many counties have sanitary engineers on their staffs, or have regional state sanitary engineers assigned to several counties. On a local level such as this, more adequate control over private water supplies may reasonably be expected. Control implies legislative support and police power, as well as extensive cooperation between the management of private water supplies and the engineers and inspectors of the health units. Until education and control are achieved, difficulties will continue to be experienced with private water supplies and the record of water-borne disease outbreaks will continue to be poor when compared with that of public water supplies.

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Recent Trends in Water Supplies

By Charles R. Cox

A paper presented on Sept. 4, 1947, at the New York Section Meeting, Plattsburg, New York, by Charles R. Cox, Chief, Bureau of Water Supply, Div. of Sanitation, New York State Dept. of Health, Albany, N.Y.

THE transition from war to peace has been so gradual and so many new problems have arisen that many of the headaches and trials associated with the war have not yet been eliminated. It is pertinent, therefore, to take stock of the current situation.

Water Supply Needs

In spite of the construction work undertaken during the depression in cooperation with such agencies as the PWA and WPA, there is a great accumulation of postponed improvements and delayed repairs incidental to the depression and to the war period.

No new planning is being undertaken through the agency of the New York State Postwar Public Works Planning Commission, with the exception of plans for sewage treatment works. Many projects already planned, however, have not been constructed because of high prices, shortages of material and labor and so forth. It is very evident, therefore, that local officials should keep in touch with developments so that construction work can be started as soon as possible.

Ground Water Resources

It is relatively easy to appraise surface water resources through a study of such factors as watershed area and runoff, but ground water is hidden and the yield of wells and springs is influenced by many uncertain factors which are difficult to appraise. Nevertheless, ground water resources are of basic value to New York State communities because, generally speaking, wells and springs yield water which needs no treatment other than, perhaps, chlorination, except when hard waters must be softened or iron and manganese removed.

The value of the ground water resources of New York State is indicated by the fact that 478 out of 875 public water supplies being operated in 1946 were secured from wells or springs. The population of about 1,500,000 served thereby is small in comparison with the 13,000,000 people served by all of the supplies in the state. The important point, however, is that wells and springs are chiefly useful to small communities which are least able to construct and operate water filtration plants needed for the effective treatment of most surface supplies. The current survey of ground water resources in New York State by the U.S. Geological Survey in cooperation with several state departments is of basic value, because the results for the entire state will serve as a needed guide for municipalities, consulting engineers and state departments interested in this field.

Flocculation and Sedimentation

New-style flocculating and clarification units developed prior to the war by several manufacturers of water purification equipment have emphasized the importance of agitating the coagulant-treated water in the presence of previously precipitated floc. If short-circuiting of basins does not occur, such water may be effectively clarified by upward flow through so-called sludge blankets where sedimentation is more rapid than the rate of upward flow. This well-known development is mentioned because it has focused attention upon the rather glaring deficiency of many old-style coagulating basins not equipped with efficient stilling baffles. For instance, many old-style basins with computed sedimentation periods of four hours or more actually have effective detention periods of less than one hour, because of short-circuiting. The new method is a challenge to those operating old-style basins to better their facilities by installing improved agitation for flocculating purposes and by employing stilling baffles to increase sedimentation efficiency.

High-Rate Filtration

The improved results secured with effective flocculation and clarification obviously reduce the load on sand filters. There is a definite tendency, therefore, for the unit rate of filtration to be increased and for coarser filter sand to be used. The most recent example in this trend is the practice at the new Chicago filtration plant, where special attention has been given to effective pretreatment. Very extensive experiments indicated the feasibility of using a unit rate of filtration of 4.0 gpm. per square foot of filter area. Although this is not the first filtration plant to be so operated, it does represent the culmination of a great deal of research disclosing the interrelationship between the size, porosity and depth of sand, the rate of filtration and the length of filter runs —assuming effective pretreatment.

Obviously, under conditions where effective pretreatment cannot be assured at all times, a factor of safety must be provided through the use of a lower rate of filtration. For instance, with delayed coagulation, experience has shown that the use of the conventional rate of filtration of 2 gpm. per square foot permits coagulation within the filters through contact phenomena. Though in theory the remedy is to improve pretreatment, actually there are many older filter plants where this cannot be assured. *Therefore, it is quite evident that the permissible rate of filtration must be appraised for each raw water and for each filtration plant, including the reliability of the operator and the type of control available.*

Diatomaceous Earth Filters

The use of diatomaceous earth filters for the clarification of water represents the only basic change in filtration practices since the rapid sand filter was developed during the period 1885–1900. As far as is known, this new type of filter has not been employed for the clarification of public water supplies in New York State, but a few units are being installed at swimming pools.

Diatomaceous earth and similar filter aids have been used by industry for many years for the clarification of various liquids. Research work by the U.S. Army during the war demonstrated that these filters were more effective in the removal of pathogenic organisms causing several tropical diseases than conventional sand filters, especially

when operated at high rates required by military exigencies.

It is premature at this time to try to determine the ultimate place of diatomaceous earth filters in water supply practices, but available data indicate that the units may be of special value in clarifying surface water from lakes and large reservoirs where high turbidities do not prevail but where algae and suspended solids may be removed without elaborate flocculating and clarifying equipment.

The amount of diatomaceous earth required as a "precoat" for this purpose is 5–10 lb. per 100 sq.ft. of effective filter (strainer) area. Additional filter aid, in amounts of 12–42 ppm., is necessary to maintain effective porosity of the material, depending upon the suspended solid content of the raw water. With waters of high color and turbidity, a coagulant is needed in addition.

The loss of head through such units varies in the range of 15 to approximately 35 psi., which is considerably greater than with conventional sand filters. Here again the relationship among rates of filtration, loss of head and length of filter runs controls the economy of treatment. Rates of 2–4 gpm. per square foot are used in public water supplies rather than the somewhat higher rates used for the army units. The size of the equipment required for this purpose can be visualized from the fact that a standard unit 20 in. in diameter has an effective filter area of about 25 sq. ft.

Free Residual Chlorination

Though free residual chlorination is facilitated when a filtration plant is available, this process fortunately may be practiced also in the absence of filtration. This is of great importance in New York State because 176, or 60 per cent, of the total of 293 surface supplies are treated by chlorination alone. Elaborate laboratory facilities are not necessary for control purposes, inasmuch as the ortho-tolidine-arsenite test distinguishes between free and combined residual chlorine in the treated water.

During the initial application of free residual chlorination, the more active residual present in water entering distribution systems will react with pipe slimes and organic deposits in water mains to form taste-producing substances. Eventually these pipe growths and organic deposits are oxidized by the chlorine, and the transition period can be shortened by thoroughly flushing the distribution system and by exercising care in the control of chlorine doses. The ultimate guide should be the presence of free residual chlorine in small concentrations in the tap water from the more remote portions of the distribution system.

Chlorine Dioxide Treatment

The use of chlorine dioxide to oxidize taste- and odor-producing compounds in water has been adopted in recent years at a number of plants. The treatment has been especially valuable in removing chlorophenol tastes incidental to the presence of industrial wastes in the raw waters, but satisfactory results also have been secured in destroying other tastes and odors.

Additional data are needed on the effectiveness of chlorine dioxide in the treatment of unfiltered supplies and of supplies in which tastes and odors are caused by algae growths. Recent literature has contained significant data showing that chlorine dioxide, either alone or in the presence of chlorine, is a satisfactory disinfectant. A test has been developed to disclose the concentration of chlorine dioxide in water so

that it is now possible to distinguish between residual chlorine and chlorine dioxide.

Fluorination of Public Water Supplies

It is premature to draw up final conclusions on the results of the demonstration being conducted by the New York State Department of Health at Newburgh to determine the effect upon children's teeth of maintaining 1.2 ppm. of fluorine in the public water supply. It will be necessary to continue dental and medical studies of children whose permanent teeth have developed subsequent to the inauguration of the treatment in May 1945, before definite evidence is available. Preliminary evidence, however, already discloses improvement in dental health in the young children of Newburgh.

The number of people with cavities in the teeth is increasing more rapidly than the extent of correction through the use of dental service by the general public. Experience has shown that any improvement through public education will be very difficult to achieve, so that any procedure which will benefit the public as a group will secure more prompt and economical results than relying upon individual action.

There is extensive precedent for treatment to remove deleterious ingredients from water, even though less than 1 per cent of a public water supply is used for potable purposes. With the exception of the treatment of several public water supplies with iodine some years ago for the prevention of goiter, there is no precedent for adding beneficial ingredients to public water supplies. On the other hand, dental surveys of communities which have developed new sources of water containing approximately 1 ppm. fluorine have demonstrated that the natural fluorides present will result in about one-third as many dental cavities as occur in communities served by water supplies containing little or no fluorine. The demonstrations at Newburgh and at about six other places, therefore, are to determine whether the application of sodium fluoride will secure results equivalent to those prevailing when the natural fluorine content of a public supply is approximately 1.0 ppm.

Sodium fluoride can be added to potable waters without any technical difficulties, through the use of inexpensive chemical feeders. The cost is about $2.50 per million gallons of water treated. This compares favorably with the cost of corrosion control, taste and odor control and other similar aspects of water treatment.

In a city with a population of 100,000 consuming 10 mgd. of water the daily cost would be $25.00 and the annual cost, $9,125. This may seem to be a large sum of money, but it is only about $0.10 per capita. On the other hand, an adequate fluorine content naturally present in potable waters has been shown to reduce the number of cavities by two-thirds.

The actual expenditure for dental care in a community using fluorine-deficient water is about $4.00 per capita per year, although this average figure should be $12.00 per year. The reduction of the need for dental care by two-thirds will therefore result in an average annual per capita saving of $8.00 to those utilizing the services of dentists to the fullest extent. The saving in the cost of the more urgently needed dental care actually utilized cannot be estimated but, if it is two-thirds of $4.00 actually spent each year on an average, the per capita saving would be about $2.50 per year. As the cost of the ap-

plication of sodium fluoride is only $0.10 per capita per year, it is evident that, if this water treatment procedure is a success, the savings to the public will be very great, not to mention the benefits of better dental health.

Until the period of controlled experimentation has elapsed and the results are available, the water works official should not add fluorine to the supply under his jurisdiction as a routine treatment procedure. The basic policy on the treatment of disease through the medication of potable water supplies must rest upon the results of the experiments and the general concurrence of medical, dental and engineering thought as crystallized in succeeding years, when experience will provide the basis for judgment.

Residential Softening Units

The demand for soft water in many communities served by hard water supplies has led to the organization of companies which rent zeolite softening units to individual property owners and service them on a monthly basis. The willingness of property owners to contract for this service at an annual charge greater than the cost per consumer of water softened by a single municipal softening plant indicates that many municipalities would secure wholehearted support from the citizens for the installation of municipal softening plants, provided public sentiment is consolidated by suitable publicity. Despite this situation, there are only thirteen municipal softening plants in New York State although 172 supplies have a hardness of 150 ppm. or more.

Water Works Schools

Although efforts were made to set up schools for Grade II water treatment plant operators in 1947, it was found impossible for the engineering schools of the state to assist in this matter because of the press of accommodating the greatly enlarged enrollment incidental to veterans' training. It is hoped, however, that schools for Grade II operators can be arranged in 1948.

Experience with the school for Grade II operators conducted by Prof. Eglof of Niagara University in 1946 demonstrated the value of holding such schools for operators within commuting distance; a course of 120 hours may be provided for 30 Saturday mornings, with sessions of four hours each. Accordingly, attempts are being made to establish at least several schools to meet the needs of operators throughout the state.

The usual schools for Grade III operators, lasting approximately three days, will be held in Albany, and in other areas if necessary.

The New York State Civil Service Dept., in cooperation with local civil service boards, has developed a policy of coordinating civil service requirements with those of Chapter XI of the State Sanitary Code enacted by the Public Health Council. Thus a certificate from the Public Health Council is a prerequisite for those water treatment plant operators employed by communities with civil service. The program of issuing such certificates to qualified operators and of providing schools for those needing additional training is therefore of basic importance. It is gratifying to note that an intensified training program is being organized by the New York State Dept. of Health to utilize more effectively the facilities of engineering schools throughout the state.

Developments in Water Chlorination Practice During 1947

By Harry A. Faber

A contribution to the Journal by Harry A. Faber, Research Chemist, The Chlorine Institute, Inc., New York.

THE American Water Works Association has made available to the water works industry a clear and reasoned statement on the vital role of chlorination in protecting public health (1): "Whatever may be said by anyone today against the use of chlorine in drinking water may be nullified by recognition of the simple fact that there are hundreds of thousands of our people today who are alive and healthy because chlorination of drinking water has been recognized by water works men as a necessary element in protection of the quality of the product."

A "Chlorine Manual" has been published (2) providing useful facts about chlorine and the proper handling of chlorine containers, recommending measures for employee protection and supplying data concerning the chemical and physical properties of chlorine. According to the representatives of one chlorine producer (3), the present shortage is caused by increased requirements for previous uses and growing needs for new uses (such as plastics, insecticides and herbicides). The shortage is expected to continue for at least two years.

In New York State (4), the value of having emergency chlorinators available has been amply demonstrated. During the past year emergency chlorinators maintained by the State Health Dept. were in use a total of 925 days, or an average of 51 days for each installation. The state points out that the only safe answer to the problem of continuous chlorination is the installation of stand-by machines so that one will always be available in the event of failure. It is stressed that, if emergency equipment had not been available, the health of water consumers in eighteen communities would have been seriously endangered. At Little Rock, Ark. (5), a portable trailer-mounted unit has been designed for the sterilization of water mains, and a standardized procedure makes this practice a routine operation.

In the field of research, studies at Harvard University (6) are being made on the action of chlorine on bacteria, cysts and viruses. These investigations are directed toward an understanding of the basic factors which affect chlorination and the possible development of a formula for effective chlorination. Factors now recognized to be of outstanding importance are: the acidity or alkalinity of the water, the contact time and the type of residual chlorine present.

Expansion of Free Residual Chlorination Practice

The present concept of chlorination, in which a distinction is made between two types of treatment (free residual

and combined residual chlorination) has been reviewed in a paper by Faber (7). The principle is set forth in a chapter of the forthcoming A.W.W.A. *Manual of Water Quality and Treatment,* which has been prepared by a committee of the Association. Definitions are now provided for specific types of chlorination and suitable control methods are available. According to Griffin (8), the break-point process as a method of providing free residual chlorination is being widely adopted. By the end of 1946 this process was reported to be in use in at least 370 water treatment plants, of which 40 are industrial supplies.

In a report to the Engineering Section of the American Public Health Assn., the Committee on Water Supply (9) discusses present trends in water treatment and gives special emphasis to the many advantages of free residual chlorination practice. At a meeting of the same association, Faust (10) of the Michigan State Dept. of Health reported that the adoption of free residual chlorination in that state improved the water quality and safeguarded it through the distribution system. In Michigan, a population of over 3,000,000 in 45 communities is supplied with water so treated. Free residual chlorination results in superior bactericidal action; improves taste, odor and color removal; eliminates aftergrowths in the distribution system; and is reported capable of inactivating the virus of poliomyelitis. The treatment is considered especially successful in small plants where facilities are inadequate.

The standards and policies established by the Illinois Dept. of Public Health (11) as part of its water supply program mark a forward step in the application of recent laboratory studies to field practice. With the chlorination studies of the U.S. Public Health Service as a basis, and with its own field studies for confirmation, definite disinfection standards are now recommended. Chlorination to provide free available chlorine residuals is preferred.

Chlorination for Disinfection

Results have been published by Spencer (13) which show that the universal chlorination of water supplies was found by military authorities to constitute the most practical safeguard against water-borne disease. Through strict control over chlorination, no outbreaks of water-borne disease occurred at army installations in the United States during the period 1942–47.

At Baltimore, Hopkins and Edwards (14) have investigated the effect of automatic chlorination of all water discharging from the open secondary reservoirs to the distribution system. The chlorine application is varied in proportion to the flow of water by means of differential convertors. Bacteriological analyses of delivered water indicate that a density (M.P.N.) of 0.1 has not been exceeded since 1940. The Baltimore study shows that no significant bacterial degradation of water occurs in the distribution system when initial disinfection is adequate and when disinfection of secondary sources is maintained.

Research has been continued by Lensen, Rhian and Stebbins (15) to determine the ability of chlorine to inactivate polio virus in water. Studies published during 1947 deal particularly with the effect of contact periods, pH values and types of chlorine residuals. The results show that the virus may be inactivated in as little as ten

minutes at pH values between 6.8 and 7.4 when the residuals present contain no more than 0.05 ppm. free chlorine. If the residual contains only chloramine (combined) chlorine residuals, at least 0.5 ppm. must be present, and the contact time must be about two hours.

Additional laboratory studies by Ridenour and Ingols (16) compare the bactericidal effect of chlorine dioxide with that of chlorine under the same conditions. On the basis of ortho-tolidine-arsenite residuals (free available chlorine), the bactericidal properties of chlorine dioxide are reported to be as great as, if not slightly higher than, those of chlorine.

A report of U.S. Army medical investigations (17) presents further data on the effectiveness of water treatment methods for the inactivation of the virus of infectious hepatitis. This disease has been shown to be transmissible by polluted water and was one of the most serious medical problems of the past war. The latest studies indicate that coagulation, settling and filtration of water deliberately contaminated with the virus will not be effective. Treatment of the contaminated water with sufficient chlorine to maintain a total residual chlorine content of 1.1 ppm. (of which 0.4 ppm. was free available chlorine) did inactivate the virus in 30 minutes.

Chlorination for Effecting Chemical Changes

Plant-scale tests described by Mathews (18) show that iron and manganese removal can be effected by free residual chlorination at normal pH values and without elaborate treatment facilities. The oxidation of manganese by chlorine is a slow reaction in a settling basin but is swift when water is filtered through an ordinary rapid sand filter.

Chlorination of raw water to maintain an adequate residual of free available chlorine is credited with rather remarkable results at the Plattsburg, N.Y., water plant (19). It makes possible the coagulation of the raw water with a much reduced dose of alum or with no alum at all, provides greatly improved disinfection and prolongs filter runs at a lower total cost of chemicals. These results are accompanied by the effective control of tastes and odors. The Plattsburg plant uses fine coal as the filter medium, and filter runs average 700 hours.

The use of chlorine for cleaning filter sand at the Hamilton, Ont., filter plant is described by Matheson (20). After two years of operation the chlorine demand of the filter sand increased, so that increasingly larger prechlorination doses were required. It was demonstrated that nitrifying bacteria were present in the filters and caused the destruction of residual chlorine. These bacteria convert ammonia to nitrites, which require chlorine for oxidation to nitrates; 1 lb. of nitrite nitrogen requires approximately 5 lb. of chlorine for this oxidation. It was found that the application of 300 lb. of chlorine to each filter ($\frac{1}{20}$ lb. per cubic foot of sand) eliminated these bacteria from the filters. It is recognized that reinfection of the filters is inevitable, but savings in chlorine have already justified the treatment.

Simmons (21) at Wierton, W.Va., has found chlorine dioxide treatment to provide the best control of tastes and odors thus far available. Treatment of this heavily polluted Ohio River supply is especially difficult, but

the application of chlorine dioxide in pretreatment (1.0 ppm.) and again after filtration (0.5 ppm.), as a safety measure, has been found successful. Chlorine dioxide is used in pretreatment both to obtain better taste and odor control and to accomplish the removal of manganese. The treatment is simple and is operated at a slightly lower over-all chemical cost than other methods.

A survey of results produced by treatment with chlorine dioxide in six water plants on the Niagara border is reported by Aston (22). Phenolic and other contamination can be successfully and economically controlled, as shown by results obtained in treating these six supplies, which are heavily polluted with industrial wastes. In discussing this paper, Faber (23) notes that the compound produced by chlorination or chlorine dioxide treatment determines whether or not a noticeable taste will be produced. It is suggested that chlorine dioxide may react with phenol to produce trichlorophenol, a compound requiring a concentration of 1 part in 1 billion of water to be apparent to the taste.

Chlorination Test Methods

Connell (24) has published a simple ortho-tolidine titration procedure for measuring free available chlorine residuals. An adaptation of this method is provided by an "eye-dropper kit" which is especially applicable to the measurement of high chlorine residuals.

An automatic residual chlorine analyzer is described by Gray and Moses (25). The equipment consists of four parts operating as a unit: (1) a heating unit maintaining water at 20°C. by thermostatic control, (2) a mixing unit in which ortho-tolidine is mixed with water, (3) a photoelectric color analyzer and (4) a commercial recording potentiometer. This unit compensates automatically for color and turbidity in water and for variations in current and provides a continuous record.

Reporting on the use of an electrophotometer for determining fluorides in water, Todd (26) calls attention to the fact that free residual chlorine interferes with the routine fluoride determination. His data indicate that 1.0 ppm. free available chlorine will show as the equivalent of 1.0 ppm. fluoride. One drop of a 10 per cent sodium arsenite solution will effect dechlorination, but even when this is done before making the fluoride test, the amount of fluoride determined will still be 0.1 ppm. too high.

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Taste and Odor Control at Shreveport

By B. G. Cole

A paper presented on Oct. 15, 1947, at the Southwest Section Meeting, Amarillo, Tex., by B. G. Cole, Chem. Engr., Water Dept., Shreveport, La.

For a period of several years Shreveport, La., has been faced with taste and odor conditions in the raw water supply, due primarily to the presence of algal growths, which are usually prevalent from the middle of May to the latter part of August. At other seasons of the year odors may be caused by decomposing vegetation. This paper will describe the research performed during 1946–47 in an effort to deliver a palatable water to consumers.

A good-tasting water is undoubtedly a prime requisite for the maintenance of cordial public relations. Those who have had or are now having experiences with foul or vile tastes and odors due principally to algae or organic matter in the water will appreciate the effect on public sentiment. During the spring of 1946 and 1947, when the taste and odor of the water in the distribution system at Shreveport was most noticeable, the public was given an explanation of the cause of the trouble; was advised that the tastes and odors were not harmful to health; and was promised that the existing condition would be corrected at the earliest possible moment. The complaints immediately dropped to a minimum and enabled the department to devote its full time and efforts to the work at hand rather than to answering consumer complaints.

Even though algae are not considered disease-producing organisms, the results of their presence in a water supply can be almost equally harmful in an indirect way. Before an epidemic of tastes and odors can be brought under control, there are some people who, rather than drink an unpalatable water, will obtain their supply from a questionable source. That water may contain harmful bacteria, yet be a clear, palatable, sparkling water.

Within the author's own experience, it was also noticed that during the past two algal seasons, when the usual tastes and odors were present in the finished water, the local bottled water company did a thriving business. It is believed, however, that this year water consumers will have no cause to buy any bottled drinking water in order to obtain a more palatable supply.

Water Supply Characteristics

Cross Lake, Shreveport's source of supply, was converted into its present area of approximately 10,000 acres by the construction of a concrete dam with a spillway 225 ft. in length, to take care of flood waters. An average depth of 9 ft. prevails over 9,000 acres of the lake, with a maximum depth of 27 ft. in the channel. The lake has

nearly 13 square miles of water surface and a capacity of 25–30 bil.gal. The watershed for Cross Lake covers an area of 264 square miles. Timber in the upper sections of the lake ranges from cypress to pine, with some oak and willow.

average of 3.37 in. during the first nine months of 1947. Air temperatures varied from a maximum of 99.0° to a minimum of 22.0°F. in 1946 and from 106° down to 18°F. through September 1947. The growth of algae in this body of water varies, depending upon,

TABLE 1

Threshold Odor Average at Cross Lake, 1946–47

Month	Lake Stage—*ft.*		Total Rainfall *in.*	Avg. Air Temp. °F.	Threshold Odor Average
	Max.	Min.			
1946					
Jan.	31.2	28.0	11.53	46	11.5
Feb.	30.9	29.2	5.39	53	8
March	30.8	29.7	5.55	61	10
April	30.0	29.6	5.32	69	10
May	30.7	29.4	9.47	71	20
June	30.9	29.6	5.18	78	18
July	29.7	29.2	4.58	82	10
Aug.	29.2	28.7	3.44	81	11
Sept.	28.9	28.4	1.54	75	13
Oct.	28.4	26.0	2.47	67	13
Nov.	29.2	28.0	6.37	58	13
Dec.	29.7	29.1	3.69	54	10
		Total	64.53		
1947					
Jan.	30.4	29.4	3.57	47	13
Feb.	30.8	29.4	3.60	43	13
March	30.8	29.5	6.19	51	13
April	30.7	29.5	6.40	67	13
May	29.7	29.4	2.84	71	18
June	29.6	29.2	2.62	81	24
July	29.1	28.2	0.84	82	18
Aug.	28.0	27.2	2.77	85	13
Sept.	27.0	26.5	3.52	78	18
		Total	30.37		

Table 1 shows the lake stages, rainfall, air temperatures and threshold odor of the raw water by months from January 1946 through September 1947. It will be noted that during 1946 there was an average monthly rainfall of 5.37 in., compared with a monthly

among other factors, the temperature and color of the water.

Generally Cross Lake is little different from other impounded water supplies, which, by virtue of their origin, invite the growth of plants and microscopic organisms.

The chemical characteristics of the raw water do not change materially throughout the year. This water falls into the class known as "low alkalinity, highly colored, swampy water." Sufficient sunlight and high temperatures in the spring give rise to abundant growths of algae and microscopic organisms. During these months, depending upon the concentration of algae, the pH in the lake water will vary from 7.0 to 8.6 and the alkalinity from 8 to 45 ppm. In January 1946 the color increased to 108 ppm.; it further increased to 115 ppm. in February and then began to decrease gradually. The increase in color was brought about by heavy rains (*see* Table 1). As the color of the water increased, the threshold odor also rose from 6.0 to 11.5. Prechlorination of the raw water reduced the threshold odor to 3.4 for the water entering the plant, and the color was reduced from 108 to 97.

TABLE 2

Pumpage and Chemical Treatments

Month	Pumpage *mil.gal.*	Alum *ppm.*	Lime *ppm.*	Carbon *ppm.*	Chlorine *ppm.*	Copper Sulfate *lb.*
			1946			
Jan.	296.075	38	27	2.5	6.4	
Feb.	237.592	34	33	3.0	5.7	
March	271.646	33	29	3.2	5.8	
April	277.474	34	22	5.5	5.6	
May	294.862	31	19	11.0	5.2	3,200
June	291.330	36	15	17.0	1.7	9,300
July	285.281	36	16	8.0	1.9	
Aug.	299.829	43	22	5.0	5.8	
Sept.	290.763	38	19	6.0	5.1	
Oct.	294.457	33	17	2.3	5.3	
Nov.	282.851	17	12		8.3	
Dec.	302.216	15	11		5.4	
			1947			
Jan.	292.448	14	11		4.2	
Feb.	258.169	17	12		4.9	
March	281.790	21	14		5.8	
April	270.861	22	15	2.6	6.1	
May	287.634	22	17	9.9	7.8	6,500
June	275.695	27	15	18.4	5.9	2,000
July	325.803	34	14	9.4	4.8	
Aug.	276.129	45	19	6.2	8.6	
Sept.	279.062	34	22	1.1	8.6	

Copper Sulfate Treatment

With the advent of heavy algal growths in the spring of 1946, the threshold odors in the raw water began increasing. It will be seen in Table 2 that copper sulfate treatment was instituted by application around the pump intakes during May and June 1946. Because of the method of

application, lack of equipment and non-coordination of the crews distributing the copper sulfate, the application was not successful in the first year. Little if any reduction in the intensity of odor was noted in the water entering the plant. In May and June 1947, however, the lake water was treated with copper sulfate around the intakes with a decided improvement in results. Enough data have been gathered during these two seasons to demonstrate that copper sulfate will eliminate the rapid growth of algae if properly applied, but this treatment must be followed by additional chemical treatment in the plant to remove or adsorb odors due to the dead algae or to micro-organisms. To improve the condition of the water in the lake, it has been planned to institute a clean-up program to remove underwater growths, such as weeds, lily pads and the like. Along with this work will be included seasonal treatment with copper sulfate, as required by the concentration of algal growths. At present it is planned to treat only the first 3,000 ft. above the raw water intakes.

Chlorine Treatment

A reduction in threshold odors was realized from superchlorination alone during that part of the year when algae concentrations are at a minimum. Color reduction and improved coagulation and cleansing of the 3-mile raw water transmission line were also noted.

The chemicals relied upon during the 1946 season of algal growths were copper sulfate, chlorine applied at superchlorination rates and activated carbon. The combination was not successful in the removal of all tastes and odors. Water from the lake was first superchlorinated and then treated in the plant with activated carbon at dosages up to 22 ppm. Chemical dosages employed during the year are recorded in Table 2.

During the heavy algae season, when threshold odor begins increasing in the raw water, it was found that a reduction in the amount of chlorine applied brought about a corresponding reduction in odor. Based on these experiences, the application of chlorine to the raw water was discontinued entirely during the months of June, July and the early part of August. The fact that the raw water contained no

TABLE 3

Chlorine Residuals and Threshold Odors

Chlorine Applied *ppm.*	Chlorine Residual, *ppm.* 30 min.	60 min.	Threshold Odor
1	0.1	0	None
2	0.2	0.1	None
3	0.3	0.3	None
4	0.8	0.5	Mild
5	2.3	1.3	Mild
6	2.1	1.8	Strong
7	2.4	2.2	Strong
8	3.0	2.7	Mild
9	3.6	4.2	Strong
10	3.9	4.0	Strong
11	5.4	4.6	Very strong
12	5.0	4.8	Very strong
13	5.7	5.0	Very strong
14	6.6	5.6	Very strong

chlorine did not decrease the threshold odor materially but changed it from a very vile chlorinous odor to a woody-fishy type. This woody odor can be more easily removed by activated carbon. Evidently, chlorination tends to convert these taste and odor compounds to a less adsorbable form.

During 1946 attempts were made to change from superchlorination to free residual chlorination, and laboratory tests were conducted with the expectation of reaching a "break-point" at approximately 8 ppm., but no dip occurred in the residual curve. According-

ing to the flash test with ortho-tolidine, the chlorine residuals were apparently in the form of free chlorine. Table 3 shows the results obtained, as well as resultant odors. Note the increase in odor with higher chlorine dosages.

During this attempt to locate the "break-point," J. A. K. Van Hasselt, Northern Regional Engineer of the Louisiana State Dept. of Health, offered his assistance and did considerable laboratory work in an effort to find a solution to the trouble. On June 5, 1946, Van Hasselt collected 5 gal. of lake water, which he tested in his laboratory at Monroe on June 8. Dosages were applied in 0.5-ppm. increments instead of the usual 1 ppm. The "break-point" was obtained after one hour of retention at 4.5–5 ppm. chlorine with very little odor remaining. Subsequent tests also showed that a break or dip would occur, but all of the water samples were held from one to three days before making the tests. Van Hasselt's findings could not be duplicated by testing freshly collected samples nor could the "break-point" be obtained on plant-scale tests.

During the spring of 1946, 9 mgd. of water was treated with chlorine dosages ranging from 100 to 1,000 lb. in an attempt to remove the woody-fishy odor as well as the chlorine-reaction odor. Ultimately, the reduction of the chlorine dosage, with final discontinuance, gave the best results at the time.

When heating water samples to about 60°C. for threshold odor tests, it was found that in some samples the odor was removed. Upon further investigation it was learned that chlorine was removed, together with the odor, after heating. The department then began to think in terms of superchlorination and dechlorination. It was found that whenever the excessive chlorine was removed the foul chlorine-reaction odor was also removed.

This theory was put into plant practice during the late fall of 1946 and early spring of 1947. Threshold odor tests conducted on water from the raw-water stage through to the filter effluent led to the belief that a solution to the taste and odor problems in Shreveport had finally been achieved. During this time, although no activated carbon was being used, there was a reduction of about ten threshold odor units. It was noted that the presence of even a trace of chlorine in the settled water would give rise to a chlorine-reaction odor, which it was assumed was being produced by the presence of nitrogen trichloride. While experimenting with superchlorination and allowing the chlorine to be removed of its own accord (no chemicals being added for dechlorination), the chlorine residual in the raw water was 2.0 ppm. with a threshold odor of 10. After the water had traveled through two settling basins and reached the top of the filters the chlorine residual dropped to 1.0 ppm. and the threshold odor to 5. No traces of chlorine were found in the filter effluent and, consequently, no trace of chlorine-reaction odor.

Because of these successful results, this method of odor removal was adapted for plant practice by adjusting the chlorine dosage of the raw water so that all of the chlorine would be dissipated by the time the water reached the end of the primary settling basins (a period of eight hours' detention). All carbon applications were discontinued in November and the above-mentioned procedure was continued until the first part of April 1947.

Chlorine Dioxide Tests

On June 5, 1946, laboratory tests were made by Van Hasselt with chlorine dioxide. These tests were conducted with the greatest possible care, in conformity with the instructions of the Mathieson Alkali Works. A series of solutions was prepared for samples resulting in dosages of 1–10 ppm. chlorine dioxide. Water samples containing the algae odors were collected from the raw, settled and filtered water. No reductions in threshold odors were realized in any dosages of the series of samples treated. The tests thus indicated that chlorine dioxide would not prove successful in removing the algae tastes and odors.

It was pointed out by Van Hasselt in a report on this work that, if by some means a pure dosage of chlorine dioxide could have been applied, the results might have been more favorable. It seems that it is necessary to generate this gas by adding an overdose of chlorine (as chlorine water) to the solution of sodium chlorite. Where chlorine had proved to cause an increase in odors, it was practically impossible to get a true picture of the action of additional chlorine unless a "break-point" could be reached. At some future date, however, it is planned to do additional work with chlorine dioxide, on a plant scale if possible, using a small filter as a pilot plant and discharging the filter effluent to waste while the experiment is being carried on.

Change in Carbon Application Point

In April 1947 the department was facing a discouraging situation, as it was rapidly becoming evident that the method of chlorination which had been practiced did not successfully remove the woody-fishy odors then coming in with the raw water. The threshold odor in the raw water began to increase from 8 in April to 12 and 15 in May. In view of the inability to produce a palatable water, carbon treatment was again resumed about midway through May 1947. Raw-water chlorination was increased from 6.1 to 7.8 ppm.

In the latter part of May and early June 1947 there was a general outbreak of foul, woody-tasting water in the distribution system, in spite of the fact that the carbon dosage had been increased to 22 ppm. By this time the results of using both activated carbon and superchlorination for the removal of the odors existing in the water supply had proved disappointing.

After conducting many series of laboratory tests to determine the correct chemical or combination of chemicals, as well as the correct point of application, the conclusion was reached that the carbon was being applied at the wrong points for best results. The carbon application was moved from the mixing basin (where a 2.0-ppm. free chlorine residual persisted) to the middle of the primary settling basin, where the chlorine residual was depleted. A second carbon dosage was applied in the secondary basin. The carbon dosage was increased from 22 to 30 ppm., which brought about a decided reduction in tastes and odors, producing a palatable tap water. The superchlorination treatment of the raw water, giving a residual of 1.8–2.3 ppm. in water entering the plant, was reduced to provide a residual of 0.2 ppm. at that point. This reduction in raw-water chlorination dosage permitted the carbon to do more work per pound applied, since part of the carbon had been consumed by acting as a dechlorinating agent instead of adsorb-

ing the unwanted woody tastes and odors.

Additional Tests

During 1947 additional tests were conducted in an attempt to find the chlorine dosage which would create a "break-point" in the raw water; this in turn, it was believed, would lead to a reduction in tastes and odors. Tests with chlorine dosages ranging from 1 to 10 ppm. showed results similar to those in 1946: no "break-point." Furthermore, at no point in this range of chlorine dosages was the treated water palatable.

TABLE 4

*Results of Chloramine Treatment of Raw Water**

Sample No.	NH_3	Cl_2	Cl_2 Residual	
			½ hr.†	2 hr.†
	ppm.			
1	0.12	0.5	0.15	0.15
2	0.25	1.0	0.40	0.30
3	0.38	1.5	0.80	0.60
4	0.50	2.0	1.20	0.80
5	0.75	3.0	1.60	1.2
6	1.0	4.0	1.8	1.4
7	1.25	5.0	2.0	1.8
8	1.50	6.0		
9	1.75	7.0		

* Cl_2–NH_3 ratio 4:1. In no sample was nitrogen trichloride present.

† Contact time.

Conclusions

A number of general conclusions were reached as a result of the work done at this time:

1. Superchlorination (7.0–8.0 ppm. chlorine applied) of the raw water to a 2.0–3.0-ppm. free chlorine residual did not remove the woody taste and odor present. This dosage of chlorine reduced the pH sufficiently to produce what was assumed to be nitrogen trichloride.

2. Superchlorination tended to set and accentuate the woody-fishy taste and odor present in the raw water at the time of these tests, thereby requiring more activated carbon to produce a palatable water.

3. Laboratory tests on the raw water, employing both superchlorination and low doses of chlorine, showed that activated carbon was more effective in removing the tastes and odors present when the latter type of chlorination was used. Similar results were found in the plant-scale application of carbon.

4. Laboratory tests showed that activated carbon was even more effective in removing tastes and odors present in the raw water when the chloramine treatment was used.

5. Treating the raw water with various dosages of chlorine and ammonia (4:1 ratio) in the laboratory did not produce the odor-bearing compounds experienced with superchlorination (Table 4).

Present Plans

Activated carbon treatment at both plants was discontinued on September 16, 1947, as the tastes and odors were at a minimum. The department now is at work on the superchlorination method of taste and odor control. The chlorine-reaction, or "nitrogen trichloride" odor is still present in the raw water, but it is eliminated at the end of the first settling basin by removing the chlorine while the water is within this basin. Using this method of treatment, very little carbon will be applied until the algae season of 1948. It is hoped to deal with the situation at that time by applying the knowledge gained during the past two seasons. Pre-

vious experiences indicate that a combination of chemicals will be necessary for the complete control of tastes and odors in Cross Lake water: (1) copper sulfate, applied to the lake as needed; (2) chloramine treatment of the raw water; and (3) activated carbon treatment in the plant.

Shreveport's experiences bring out the fact that every method of controlling tastes and odors will not necessarily be successful in all waters, at all times and under all conditions. Each individual water supply is a problem in itself and must be dealt with accordingly.

Acknowledgments

The author wishes to acknowledge the assistance received while working to bring about a solution of the taste and odor problem in Shreveport. The department's appreciation is extended to the Louisiana State Department of Health for its advice and assistance, and to J. A. K. Van Hasselt, Northern Regional Engineer, for his considerable laboratory and engineering work. The department is also grateful to the Industrial Chemical Sales Div., West Virginia Pulp & Paper Co., for its help during the past algae season.

Distillation of Sea Water by the Vapor-Compression Method

By John J. Campobasso

A contribution to the Journal by John J. Campobasso, Engr., Cambridge Div., E. B. Badger & Sons Co., Cambridge, Mass.

At present distillation is the only practical process known for treating sea water to render it suitable for drinking, boiler feed or general use where large concentrations of salts or a high degree of corrosiveness cannot be tolerated. Unless fresh water is transported over long distances, the sea is the only source of water available not only to ocean-going vessels, but also to thousands of arid islands, millions of square miles of arid coast, and large areas located on the lower reaches of tidal rivers.

Until recently all large-scale commercial equipment manufactured for the distillation of sea water consisted of steam-fired single- or multiple-effect evaporators. After many years of extensive research, however, and as a result of the experience gained in building and operating several thousand units, the vapor-compression distillation unit is now ready to assume a leading role in sea water distillation plants.

Description of Equipment

The vapor-compression distillation unit consists of four main pieces of equipment (Fig. 1) assembled together as a complete operating unit: (1) a power unit, (2) a vapor compressor, (3) an evaporator and (4) heat exchangers.

The power unit can be one of any of the common types of drivers, such as electric motor, diesel or gas engine, steam turbine and the like. This unit supplies the motive power to drive the vapor compressor or heat pump.

The vapor compressor is specially designed to compress steam from approximately atmospheric pressure to a higher pressure and temperature. Thus the required heat is added to the system. The compressor can be of the positive-displacement or centrifugal type, depending on the size and characteristics desired.

The evaporator is a standard vertical evaporator, sometimes referred to as the "calandria" type. The boiling of the salt water takes place inside of the tubes, and the steam thus generated is compressed and returned to the steam chest (the space between the tubes), where it is condensed to form the distillate. Because of the rapid rate at which corrosion takes place, evaporators destined for use on sea water should be carefully constructed of specially selected, nonferrous metals, preferably nickel alloys.

The heat exchangers are used to heat the incoming sea water feed by cooling the outgoing distillate and outgoing brine blowdown. Like the evaporator, surfaces in contact with sea water and brine should be made of selected alloys.

Operating Principle

The vapor-compression distillation unit, by utilizing the "heat pump" principle of recycling the latent heat of evaporation, not only eliminates the use of direct-fired equipment, but also shows a remarkable fuel economy over other types of distillation equipment. The distillation is accomplished through the use of the heat added to the system by compressing the low-pressure vapor leaving the evaporator to a higher pressure and temperature before it is condensed.

The heat cycle involved is illustrated in the flow diagram (Fig. 1). The electric motor operates a vapor compressor. When the sea water inside the tubes of the evaporator reaches its boiling-point, the compressor sucks in the vapor produced and compresses it, thus raising the "heat gradient" sufficiently to allow it to flow back to the same evaporator-condenser (the outside tube surfaces of the same evaporator). Since the total heat content of a pound of steam entering the evaporator is only slightly greater than the total heat content per pound of steam leaving, it is readily seen that only a minimum amount of work need be done to raise the steam to the required "heat gradient." As shown in the flow diagram, the steam is condensed, withdrawn from the condenser as distilled water and then pumped through heat exchangers, where it heats the incoming cold sea water feed to the evaporator. The concentrated brine is continuously removed through a blowdown system and passed through heat exchangers, also to help heat the cold feed. Since the radiation losses and heat lost in the distilled-water circuit tend to remain constant, the only variable is the amount of feed water and, consequently, the amount of heat dissipated in the blowdown. Thus operational balance is easily obtained automatically or manually by controlling the amount of feed water with a regulating valve. Should it be desirable to maintain a constant amount of blowdown, operational balance can be obtained by controlling automatically

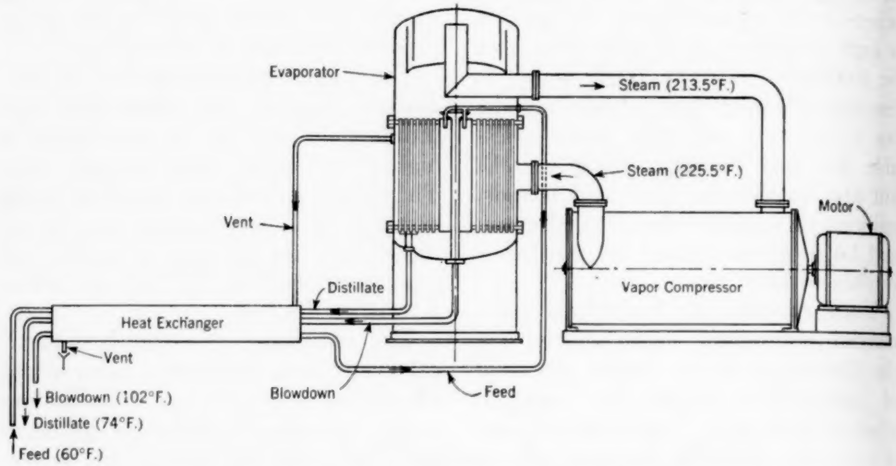

FIG. 1. Vapor-Compression Distilling Unit Flow Diagram

a small amount of auxiliary heat added to the system at a convenient point.

As is true with all types of evaporating equipment, scale forms on the heated surfaces and must be removed. The frequency of scale-removing operations depends on the amount and character of the scale. When using straight sea water for feed, the amount and character of the scale are such that operating cycles of 700 hours between cleanings are obtainable. The scale deposited on the tubes, being relatively pure magnesium hydroxide, is readily removable by an acid salt treatment requiring about two hours' time. When the parts of the equipment that are in contact with sea water and concentrated brine are constructed of properly selected alloys, there can be no danger from corrosion, either from sea water or from the acid solution.

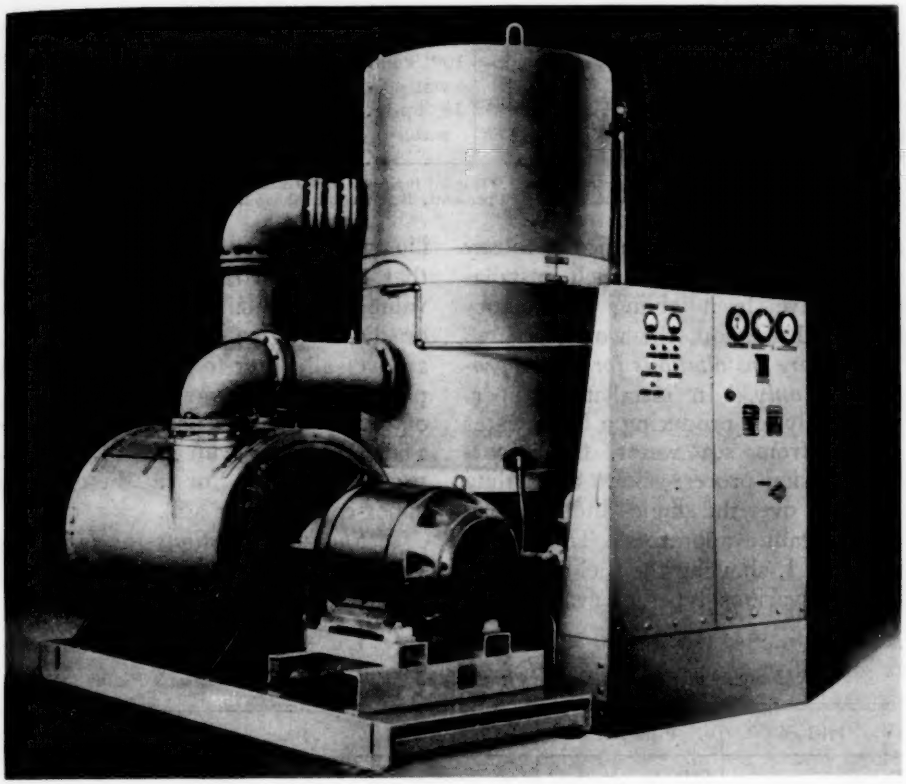

FIG. 2. Motor-driven Vapor-Compression Still

Typical Applications

A discussion of the uses of vapor-compression distillation equipment for the distillation of sea water can be divided into four categories.

1. *Aboard sea-going vessels.* The story behind the use of vapor-compression distillation units for supplying all the fresh water requirements for ships powered by internal-combustion engines is too well known to need re-

TABLE 1

*Fuel Consumption in Sea Water Distillation Plants**

Type of Plant	Amount of Steam or Power to Evaporators	Fuel Fired *1,000 Btu./hr.*	Water Produced per 1,000 Btu. *lb.*
Oil-fired boilers, single-effect evaporators	1 lb. steam per 0.9 lb. water	12,730	0.655
Oil-fired boilers, double-effect evaporators	1 lb. steam per 1.6 lb. water	7,150	1.150
Oil-fired boilers, triple-effect evaporators	1 lb. steam per 2.2 lb. water	5,220	1.590
Oil-fired boilers, quadruple-effect evaporators	1 lb. steam per 3.2 lb. water	3,590	2.320
Oil-fired boilers, condensing turbogenerator, motor-driven vapor-compression evaporators	100 kwhr. per 1,000 gal. water	1,050	7.930
Diesel-driven vapor-compression evaporators	76 hp-hr. per 1,000 gal. water	770	10.810

* Based on a distilled water production of 1,000 gph.; fuel: oil, 18,500 Btu. per pound; efficiency: boiler—80 per cent, turbogenerator—45 per cent, motor—90 per cent, diesel engine—0.555 lb. per brake horsepower.

telling at this time. Suffice it to say that several thousand such installations have been giving satisfactory service throughout the world.

2. *Shore installations for water production only.* In installations operated solely for producing a fresh water supply from sea water, the vapor-compression process shows a startling economy over the single- and multiple-effect steam evaporators. The figures in Table 1, showing the fuel consumption for various types of evaporators, illustrate this point. It should be noted that this comparison is based on the value of the fuel fired to the boilers or diesel engine and therefore gives an over-all water-to-fuel ratio for each plant. This ratio varies from 0.655 lb. of water produced per 1,000 Btu. for a single-effect steam still to 10.81 lb. per 1,000 Btu. for a diesel-driven vapor-compression still.

3. *Shore installations for producing steam, power and water.* No general statement can be made concerning the

TABLE 2

Summary of Comparative Investment and Fuel Consumed at Various Plants

Product	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
Steam (20,000 lb./hr.)	Oil- or gas-fired boilers, 575 lb.	Oil- or gas-fired boilers, 275 lb.	Oil- or gas-fired boilers, 75 lb.	Oil- or gas-fired boilers, 75 lb.
Power (4,000 kw.)	Back-pressure turbogenerator	Condensing turbogenerator	Diesel-driven generators	Diesel-driven generators
Water (300,000 gpd.)	Triple-effect evaporators	Motor-driven vapor-compression evaporators	Motor-driven vapor-compression evaporators	Diesel-driven vapor-compression evaporators
Investment	$2,259,000	$2,260,000	$2,352,400	$2,126,000
Fuel Fired—*1,000 Btu./hr.*	143,800	159,000	91,200	89,400

selection of evaporators to be used in this type of plant, since the proper evaluation of such equipment depends on many variables peculiar to each plant. Such factors include location; type of fuel; variations in demand for power, steam and water; skill of operators and so forth.

TABLE 3

Typical Analyses of Boston Harbor Feed Water

CHARACTERISTICS

Appearance: clear, with slight sediment
Color: none
Odor: none
Taste: salty
pH as received: 7.6
pH after boiling: 8.9

CHEMICAL ANALYSIS

Substance	*ppm.*
Total dissolved solids	40,333
Organic matter	10,080
Mineral matter	30,250
Silica as SiO_2	2
Calcium as Ca	371
Magnesium as Mg	1,091
Iron as Fe	0.05
Sodium as Na	9,568
Sulfate as SO_4	2,470
Chloride as Cl	16,666
Bicarbonate as HCO_3	171
Oxygen consumed	32
Total hardness	5,316
Starch	Absent
Total nitrogen	2.1
Nitrites	0.05
Nitrates	Absent
Albuminoid ammonia	0.5

BACTERIOLOGICAL ANALYSIS

Total count per milliliter: 50 colonies
Coliform group tests: positive

In this category also, the greatest single advantage of the vapor-compression method is the economy of operation, particularly in plants required to produce electric power and water only. Another distinct advantage which this method has over the single- or multiple-effect evaporator is its complete freedom from large volumes of condenser water.

An insight into the scope and economics of such a plant can be obtained from Table 2, which summarizes the comparative investment and fuel consumption of typical plants using various types of equipment. Production requirements are: a net of 20,000 lb. of low pressure steam per hour, 4,000 kw. of electric power and 300,000 gpd. of fresh water distilled from sea water. The plant utilizing diesel-driven generators and diesel-driven vapor-compression distillation units required the lowest initial investment and lowest fuel consumption.

4. *Boiler feed installations for central stations.* The use of motor-driven vapor-compression distillation units for the preparation of evaporated boiler feed make-up is advantageous because: (1) they are self-contained units of the "package plant" type; (2) they are motor-driven accessory equipment, independent of the station steam cycle; (3) they are not required to operate at times of station peak load; (4) they eliminate the necessity of extracting and conveying large quantities of steam from the main turbine to the evaporators, a feature which might result in a material saving in the initial cost of the turbine installation; and (5) the quality of the distillate produced is extremely high, as shown by typical analyses (Tables 3–5).

TABLE 4

Typical Chemical Analysis of Blowdown

Substance	*ppm.*
Silica as SiO_2	4.0
Calcium carbonate as $CaCO_3$	140.0
Calcium sulfate as $CaSO_4$	3,059.0
Magnesium sulfate as $MgSO_4$	4,788.0
Magnesium chloride as $MgCl_2$	4,906.0
Sodium chloride as NaCl	63,311.0

An idea of the operating economy of the vapor-compression still, as compared with that of the single-effect turbine-extraction evaporator, in a central station can be obtained by a study of the heat balance sheet for a recent development. The operating conditions for the station are: initial steam—850 psi. (gage), 900°F., T.T.,* 1453.1 H.†; condensation at 1½ in. mercury, 1,009.9 H.; extraction point for evaporator steam—66.40 psia., 441°F., 1255.5 H.; make-up heated to 240°F. at de-aerating heater. A single-effect evaporator requires 1.00 lb. of steam for 0.88 lb. of make-up; the cost of steam at the throttle is 30¢ per 1,000 lb.; and the cost of energy is 3 mils per kilowatt-hour.

TABLE 5

Typical Analyses of Distilled Water

CHEMICAL ANALYSIS

Total solids	4.2 ppm.
Total chlorides	0.8 ppm.
Nitrites, nitrates, albuminoid ammonia, free ammonia, carbon dioxide, sulfates, calcium, nickel, copper, tin, lead	Absent

BACTERIOLOGICAL ANALYSIS

Total count per milliliter: 28 colonies
Coliform group presumptive test: negative

Under the above conditions, it was found that the additional steam at the throttle required to operate the single-effect evaporator was 4,210 lb., representing a cost of $1.26 per 1,000 gal. of make-up produced. With a motor-driven vapor-compression evaporator, the cost of power would be 30¢ per 1,000 gal. and the cost of steam to heat the make-up from 70° to 240°F. would be 18¢, or a total cost of 48¢ per 1,000 gal. of make-up produced.

Figure 2 shows a photograph of a recent installation of this type. The unit pictured is motor-driven and has a capacity of 400 gph.‡

Water Quality

A properly designed vapor-compression still produces a pyrogen-free, sterilized, distilled water, with a negligible content of total dissolved solids and gases. The water meets all the U.S.P. requirements for water used in the manufacture of pharmaceuticals. Because water of such high purity is, of course, not necessary for general potable use, the distillate can be blended with the proper quantity of blowdown to give a product having the desired content of the various dissolved salts present in sea water, or else the salts can be added individually as required.

If the water is for general use and no special precautions are taken to prevent corrosion in pipelines and storage tanks, it is recommended that the pH be adjusted to the proper value to minimize the corrosive effect of the distilled water.

* Total temperature, including superheat, if any.

† Total heat (Btu. per pound).

‡ A Badger-Kleinschmidt vapor-compression still, produced by E. B. Badger & Sons Co., Cambridge, Mass.

Financing Water and Sewage Works Improvements

By Grant S. Bell

A paper presented on Sept. 23, 1947, at the Kentucky-Tennessee Section Meeting, Louisville, Ky., by Grant S. Bell, Partner, Howard K. Bell, Cons. Engrs., Lexington, Ky.

ALTHOUGH the problems of financing water and sewage works improvements are nationwide in scope, a closer insight may be obtained by an analysis confined to a specific area. This paper will therefore deal with those aspects which affect cities of various sizes in Kentucky and Tennessee.

Conditions Retarding Construction

With the termination of hostilities, great hopes were envisaged for new construction to handle rapidly increasing loads. But, first, the scarcity of materials and, then, the lack of competition for construction work dampened these hopes. Because material and equipment deliveries could often not be made within one year—particularly in plant construction—contractors available for such work were scarce and they hesitated to forecast their costs so far ahead. In retrospect, good reasons can be seen for their timidity.

By the spring of 1947, although material deliveries were slow, the extreme scarcities had been relieved, and much of the uncertainty about time of delivery had been removed. This stimulated bidding, and the number of bids approached normality. Projects for which owners had previously purchased, and now had on hand, the major materials in short supply were of the most interest to contractors. This was one of the many proofs of the wisdom of ordering early and then waiting, regardless of escalator clauses, instead of waiting to order. Materials ordered in the fall of 1946 had almost all been delivered by June 1947 and were being installed in the fall of that year.

To resume the chronology of events affecting construction, the next factor retarding the realization of construction dreams, after they became physically possible, was the mounting cost. The increasing revenues since 1941 had led to the assumption that utilities were in better financial condition to expand than ever before. Utilities were making out well on prewar investments even with rising operating costs. Money was readily available at interest rates about half of what they were before the war. Construction prices, however, ranged from 70 to 165 per cent above the prewar levels of the PWA construction period of 1938. For large projects this made yearly costs for interest and bond retirement so large that they could not be covered by revenues based on water rates set between 1900 and 1938, when the dollar would purchase two to four times as much as it will today.

TABLE 1

Water and Sewage Works Construction Prices, 1938 and 1947

Item	Quantity	Materials or Labor			Construction Unit			Over-all Construction		
		Price—$		Increase per cent	Price—$		Increase per cent	Price—$		Increase per cent
		1938	1947		1938	1947		1938	1947	
Water filtration and pumping plants										
700-gpm. plant	1							59,000	139,000	136
350-gpm. plant	1							43,000	113,000	163
250-gpm. plant	1							22,000	49,000	123
Std. dry chem. feed machine	1	305	405	33						
250-gpm. centrifugal pump, 20-hp. motor	1	500	800	60						
Common labor	1 hr.	0.35	0.80	129						
Carpenters	1 hr.	0.90	1.50	67						
Complete sewage treatment plants										
For 7,000–9,000 pop.	1							81,000	195,000	141
For 3,500–4,500 pop.	1							45,000	105,000	133
For 2,400–2,600 pop.	1							36,000	80,000	122
For 1,000–2,000 pop.	1							27,000	60,000	122
Concrete in water and sewage plants	1 cu.yd.				25.00	60.00	140			
Water lines, cast-iron, bell-and-spigot		Pipe			Trenching and Laying					
12 in.	1 ft.	1.93	3.18	65	0.80	1.47	84	2.73	4.65	70
10 in.	1 ft.	1.53	2.40	57	0.52	1.05	102	2.05	3.45	68
8 in.	1 ft.	1.10	1.84	67	0.39	1.03	164	1.49	2.87	93
6 in.	1 ft.	0.75	1.29	72	0.37	0.91	124	1.12	2.20	96
4 in.	1 ft.	0.55	0.88	60	0.35	0.74	112	0.90	1.62	80
2 in.	1 ft.	0.24	0.35	46	0.33	0.90	173	0.57	1.25	119
Fittings	1 lb.	0.058	0.113	95	0.012	0.012	0	0.07	0.125	64
Sanitary sewers, v.c., 4–6-ft. trench										
12 in.	1 ft.	0.36	0.65	81	0.58	1.70	193	0.94	2.35	150
10 in.	1 ft.	0.29	0.50	72	0.58	1.40	141	0.87	1.90	118
8 in.	1 ft.	0.17	0.34	100	0.56	1.31	134	0.73	1.65	126
Manholes	1							65.00	157.00	142
Solid rock excavation in trench	1 cu.yd.				4.90	9.90	102			
Earth-fill dams										
Stripping	1 cu.yd.				0.50	1.22	144			
Rolled earth fill	1 cu.yd.				0.47	0.62	32			
Concrete	1 cu.yd.				20.00	40.00	100			
Cement	1 sack	0.50	0.79	58						
Earth excavation	1 cu.yd.				1.85	1.25	*−32*			
Rock excavation	1 cu.yd.				4.10	11.90	190			
Riprap, dry	1 sq.yd.				1.00	3.05	205			
Riprap, grouted	1 sq.yd.				1.95	5.20	165			

TABLE 1—*Continued*

Item	Quantity	Materials or Labor			Construction Unit			Over-all Construction		
		Price—$		Increase	Price—$		Increase	Price—$		Increase
		1938	1947	*per cent*	1938	1947	*per cent*	1938	1947	*per cent*
Concrete reservoirs in ground										
50,000-gal.	1							3,100	7,000	126
Concrete	1 cu.yd.				25.00	47.00	88			
Steel water tanks on ground										
450,000-gal.	1							13,750	22,000	60
400,000-gal.	1							11,600	18,750	62
200,000-gal.	1							6,700	12,200	82
50,000-gal.	1							3,200	5,900	84
Elevated steel tanks and towers										
200,000-gal.	1							21,500	35,800	67
150,000-gal.	1							14,000	26,700	91
100,000-gal.	1							9,800	20,000	104

Effect of Retarded Construction

Construction prices will continue to rise. Demands on utilities will continue to mount at an accelerated rate, yet the deferment of construction remains the rule. If the present situation continues, public utilities may find themselves in a dilemma similar to that of our educational system. Drastic revision and action will become necessary in order to save the service. Breakdowns in service, or inability to take on new customers, will be the unfortunate advertisement of the true picture. A concerted effort must therefore be made very soon to educate the public to the need for expansion.

A principal component in the cost of water and sewer service over a long period is construction, and it is probably the most expensive item in present-day economy. Just as a working man cannot be expected to labor at a 1938 wage with food and other essentials costing twice as much, so a water or sewage works cannot be expected to buy needed construction to supply service at rates based on conditions prior to 1938. The effect will be similar to that on commodities held to prewar prices by OPA restrictions: the consumption will be controlled by a dwindling supply or an inability to serve rather than by the price.

Rising Wages

Because the cost of construction is so vital to utilities, the forces behind its unprecedented rise should be analyzed. Any study of the cost of construction since the low of 1933 shows that it has increased in proportion to the cost of labor and that the usual postwar scarcities are not the main cause of its rise, as it was rising at almost the present rate before the war.

The common-labor building wage in Kentucky and Tennessee has risen from 25¢ an hour in 1933 to 35¢ in 1938, 60¢ in 1941 and 80¢ in 1947.

Except for the war years, there has been a 10–15 per cent increase in wages yearly. Since even the cost of raw materials is mainly the cost of the labor of getting them out, such raises, when not based on increased productivity, are simply inflationary. Only by new machinery, new technologies and greater effort can the productivity per man—and thus the national wealth and the laborer's purchasing power—be increased.

Amount of Construction Price Rise

The 70–165 per cent increase in water and sewage works construction prices in Kentucky and Tennessee over prewar prices (see Tables 1 and 2) has been greater than the increase in the general price level and greater than the 33–100 per cent increase in the price of materials for such construction. The realization of this fact has caused the rejection of most of the bids on water and sewage works construction in Kentucky and Tennessee since the war. Only in really urgent cases have contracts been let.

TABLE 2

Comparison of Water and Sewage Construction Prices, 1938 and 1947

Item	Average Increase—*per cent*		
	Materials or Labor	Construction Units	Over-all Construction
Standard equipment	47		
Cast-iron pipe	66	126	88
Vitrified clay pipe	84	156	131
Common labor	129		
Carpenters	67		
Concrete		109	
Rock excavation		146	
Water filtration and pumping plants			141
Complete sewage treatment plants			129
Steel water tanks on ground			72
Elevated steel tanks and towers			87
Water works			97
Sewage works			130

The result of all the wage increases has been to keep prices and wages relatively on the same plane, with the sufferers being the constant-income groups, such as utilities and salaried personnel, the holders of insurance and annuities, and older people dependent on their money savings. The chief gains have been made by the property owners whose structures have increased in value relative to present reproduction costs. New capital investment cannot compete with the established prewar investment.

The highest construction prices were received in 1946 and were caused by the uncertainty of delivery of materials and the scarcity of bidders. This condition was somewhat corrected in the spring of 1947 and construction bids yielded prices 6–40 per cent lower than in 1946. By the summer of 1947 it was definitely revealed, by wage increases in coal, steel and other basic industries, that material prices would

continue to rise. Construction prices have leveled off from the brief decline, and increases in material and labor costs may be expected to cause construction prices to resume the steady climb prevalent from 1938 to 1941.

Only a greater productivity of labor and a greater competition for jobs by labor and contractors can result in lower prices. With the existing backlog of construction ready to be let even at the slightest indication of the leveling off of prices, such competition cannot be expected to increase to the point where it will be an important factor within the next few years.

An ample supply of materials for construction may not be realized for an indefinitely long period, depending on the monopolistic power of organized labor to retard production in key industries, such as coal and steel. If these were overproduced, the serious effect of labor's weapon, the strike, would be removed and the monopolistic power lost. Thus, strikes are, and no doubt will be, timed ahead of ample production.

Need for Increased Rates

Water works management has always expected to operate on a fixed-rate basis. It will have to abandon such a policy to meet the present condition of steadily increasing costs. The public has accepted 50–100 per cent increases in prices of most of the essentials for living, yet water rates remain the same as in 1933. If they are not raised soon, the general impression will be that such rates in low-cost and normal times were much higher than they should have been. Water works, however, are simply cashing in on their prewar investments in relatively low-cost construction.

This is particularly true of works founded in the PWA era of the 1930's. The rapid increase of wages and prices compared with water rates has caused small-town works to add customers more rapidly than had been expected.

TABLE 3

*Average Water Rates for 26 Cities of Various Sizes**

Item	Under 2,000 Pop.	2,000–5,000 Pop.	5,000–12,000 Pop.
No. of years in effect†	12	12	11
Minimum charge	$1.61	$1.33	$1.32
1st 1,000 gal.	0.78	0.65	0.67
2nd 1,000 gal.	0.61	0.59	0.50
3rd 1,000 gal.	0.61	0.54	0.46
4th 1,000 gal.	0.56	0.52	0.43
5th 1,000 gal.	0.51	0.49	0.42
1,000 gal. units			
6–10	0.49	0.46	0.38
11–15	0.40	0.41	0.34
16–20	0.37	0.41	0.31
21–25	0.36	0.39	0.26
26–30	0.32	0.35	0.25
31–35	0.31	0.35	0.24
36–40	0.31	0.35	0.24
41–45	0.31	0.33	0.22
46–50	0.30	0.33	0.20
51–75	0.29	0.31	0.19
76–100	0.28	0.31	0.18
101–200	0.25	0.25	0.17
201–300	0.25	0.25	0.17
301–400	0.25	0.21	0.16
401–500	0.25	0.20	0.16
Over 500	0.25	0.20	0.16

* Average for each classification.
† As of 1946.

This condition, in conjunction with the fact that such utilities were indebted for only 55 per cent of their cost and that the construction has been so recent as to preclude the need for extensive replacement or expansion at present, has made them more successful municipal businesses than had been

TABLE 4

Comparison of Water Works Operating Data in 1940 and 1946 for Cities of Various Sizes

Item*	Unit	Under 2,000 Population		2,000–5,000 Population		5,000–12,000 Population	
		1940	1946	1940	1946	1940	1946
Population		1,183		3,194		7,484	
Per customer		4.6		4.2		4.4	
Number of customers		257	330	765	976	1,699	2,136
Increase, 1940–46			73		211		437
Percentage increase	%		28.4		27.5		25.7
Water consumption	gpd.	45,392	74,622	192,527	285,909	613,490	770,282
Increase, 1940–46	gpd.		29,230		93,382		156,792
Percentage increase	%		64.5		48.5		25.2
Per customer	gpd.	176	226	251	293	361	361
Increase per customer, 1940–46	gpd.		50		42		0
Per capita	gpd.	38		61		82	
Outstanding bonded debt	$	44,062	33,250	78,750	46,500	222,715	185,758
Gross revenue	$/yr.	7,361	10,765	20,777	28,214	48,812	66,608
Increase, 1940–46	$/yr.		3,404		7,437		17,796
Percentage increase	%		46.3		35.8		36.4
Per customer	$/yr.	28.65	32.60	27.10	28.90	28.70	31.20
Increase per customer, 1940–46	$/yr.		3.95		1.80		2.50
Per 1,000 gal. pumped	$	0.444	0.395	0.295	0.270	0.218	0.237
Interest and bond retirement	$/yr.	2,858	2,850	3,633	4,402	14,448	13,469
Operating expense	$/yr.	3,799	5,950	12,482	17,003	22,563	32,071
Percentage increase	%		56.6		36.2		42.1
Per 1,000 gal. pumped	$	0.229	0.218	0.178	0.163	0.101	0.114
Total cost†	$/yr.	6,657	8,800	16,115	21,405	37,011	45,540
Increase, 1940–46	$/yr.		2,143		5,290		8,529
Percentage increase	%		32.2		32.8		23.0
Per customer	$/yr.	25.90	26.67	21.10	21.90	21.70	21.30
Increase per customer, 1940–46	$/yr.		0.77		0.80		*−0.40*
Per 1,000 gal. pumped	$	0.402	0.323	0.229	0.205	0.116	0.162
Surplus‡	$/yr.	704§	1,964§	4,662	6,809	11,801	21,068
Increase, 1940–46	$/yr.		1,260		2,147		9,267
Percentage increase	%		179		46		78.5
Net revenue per 1,000 gal.	$	0.042	0.072	0.066	0.065	0.052	0.075

* Items are averaged in each size classification.
† Retirement and operating expense.
‡ For extensions and improvements.
§ One town showed loss.

anticipated in the original financial prospectus.

If their 250-gpm. works were installed today without federal assistance, they would have to carry a bonded indebtedness of about $160,000, instead of the average $45,000 with PWA assistance in 1938. This would add approximately $7,200 to their present yearly expenditure of about $8,800. To cover a $16,000 annual operating and debt retirement cost, the average rates for small towns under 2,000 population would have to be doubled. The present average minimum of $1.61 per month (Table 3) would have to be raised to above $3.00 if the entire works were built today. Though these water works built just before the war seem prosperous today, their present average yearly surplus of $2,000 would finance only $18,000 worth of improvements and extensions, which is not much physical construction now.

Many of these small towns have been eager to obtain sewer systems since the war. Estimates showed that financing would require minimum charges of $2.50 and up per month for sewer service. Such charges are considered unacceptable to the public at the present time.

Value of Water Service

Water works perform a service which is taken so much for granted that few citizens, except where water shortages have occurred, realize the labor it saves and the necessity it is to health in populated places. The water works, in delivering 3,000 gal. monthly to a residence, purifies 834 lb. of water per day, transports it several miles—generally raising it over 100 ft. to the consumer's house—holds it ready under pressure for the moments when it is needed and, in conjunction with the sewage works, transports sewage and many other wastes for miles and cleans up the mess—all for under 7¢ per day in the smallest towns. Where, in all our industrial system, is so much work performed for so small a charge? In comparison with other things bought today, water

TABLE 5

Water Works Financing and Improvements for Cities of Various Sizes

Item	Under 2,000 Population	2,000–5,000 Population	5,000–12,500 Population
Extensions and improvements surplus will carry at 2¼ per cent interest for 20 yr.	$18,300	$78,000	$241,000
Water works impounding surplus for future improvements—*per cent*	75	37	50
Water works charging city for fire hydrant rental—*per cent*	50	25	58
Water works needing improvements and expansion of source of supply, pumping, treatment, main distribution or storage facilities—*per cent*	87	75	83
Water works needing extensions to supply requests for service—*per cent*	67	75	83
Average number of unfilled requests for water service	19	48	129

and sewer service at twice its present cost would be cheap. It would, however, require the cessation of existing service for a brief period to prove this statement to most of the citizenry.

Load and Financial Comparisons

Many towns kindly responded to the request for data on their works as of 1940 and 1946. The water works data received have been averaged in three classifications, according to population: under 2,000; 2,000 to 5,000; and 5,000 to 12,000. Some interesting results have been calculated which are recorded in Tables 4 and 5. The sewage works data were too meager to average except in the 1,000–4,000 population range (Tables 6 and 7). Most of the sewer systems were not set up on a sewer service charge basis, being financed by general obligation bonds or by the water works and operated by city forces or the water works.

It is interesting to note that from 1940 to 1946 the number of customers for all classes of water works increased about 27 per cent. The greatest percentage increase in water consumption was in the smaller towns, and amounted to 64 per cent, while in the larger cities consumption increased only 25 per cent. All classes showed a considerable reduction in bonded indebtedness. The smaller towns were ahead also on increase in gross revenue, attaining a 46 per cent increase compared with one of 25 per cent in the larger towns. But the smaller towns experienced a 57 per cent rise in operating costs, compared with a 26 per cent rise in the medium-sized cities and a 42 per cent rise in the largest cities. Total cost increases, including operation and debt retirement, were more nearly alike for all three classes, being 32, 33 and 23 per cent.

TABLE 6

*Comparison of Sewage Works Operating Data in 1940 and 1946 for Small Towns**

Item	Unit	Year	
		1940	1946
Population		2,610	
Per customer		6.6	
No. of customers		398	534
Increase, 1940–46			136
Percentage increase	%		34.2
Sewage flow†	gpd.	101,500	169,500
Increase, 1940–46	gpd.		68,000
Percentage increase	%		67
Per customer	gpd.	255	317
Increase per customer, 1940–46	gpd.		62
Per capita	gpd.	39	
Outstanding bonded debt	$	48,750	36,125
Gross revenue	$/yr.	5,470	7,845
Increase, 1940–46	$/yr.		2,375
Percentage increase	%		43
Gross revenue per customer	$/yr.	13.75	14.70
Increase per customer, 1940–46	$/yr.		0.95
Per 1,000 gal.	$	0.148	0.127
Interest and bond retirement	$/yr.	4,238	3,512
Operating expense	$/yr.	2,086	2,995
Percentage increase	%		43.5
Per 1,000 gal.	$	0.056	0.048
Total cost‡	$/yr.	6,324	6,507
Increase, 1940–46	$/yr.		183
Percentage increase	%		3
Per customer	$/yr.	15.90	12.20
Decrease per customer, 1940–46	$/yr.		3.70
Per 1,000 gal.	$	0.171	0.105
Surplus§	$/yr.	deficit	1,338
Net revenue per 1,000 gal.	$		0.022

* Average for Kentucky towns with 1,000–4,000 population.
† Dry weather.
‡ Retirement and operation expense.
§ For extensions and improvements.

It should be noted that in 1946 the total cost of 32¢ per 1,000 gal. of water in the smaller towns was just twice the cost in the largest class (16¢ per 1,000 gal.), but the rates were only about 12–16 per cent higher; nevertheless all three groups had a net profit of 7¢ per 1,000 gal. The gross revenue per customer was also practically the same, approximately $32.00 per year, or $2.67 per month. The only factor that would allow this peculiar situation is that the larger towns sell a much greater portion of their water to large customers at below 20¢ per 1,000 gal. The small towns would indeed be in an unfortunate position if many large customers were to take water at their upper-bracket rate of 25¢ per 1,000 gal., making necessary an increase in facilities to meet the additional load.

The annual surplus, for the small towns, jumped from the dangerously low figure of $700 in 1940 to $2,000 in 1946. The middle-sized towns enjoyed a 46 per cent increase and the largest, a 78 per cent increase. The small towns could finance $18,000 worth of additional bonds for construction now; the middle-sized ones, $78,000; and the large ones, $240,000. Such bond issues would, however, buy only half as much construction as before the war.

Results of Increased Loading

The 64 per cent increase in water consumption in the small towns has usually not brought on the necessity for any large plant and supply expansion. Most of the works are comparatively new and their minimum capacity of 250 gpm. for fire service has afforded a great safety factor over the load. The middle-sized towns, because of the 48 per cent increase in water consumption and their desirability as a location for certain heavy water-consuming industries, are often really pressed for capacity, from the source of supply on through the distribution system. Their 0.4–0.5-mgd. plants are now running over fourteen hours a day to keep up. Many supplies are proving too small in dry weather, and distribution systems are showing a surprising loss of head on high points remote from storage tanks. Industrial applications for water are being turned down and the water works are considered by commercial interests to be retarding the growth of the towns. Investigation has shown that the towns cannot increase their capacity at present-day prices and sell additional water at the existing rates established prior to 1935. Therefore, with no likelihood of a decrease in construction prices, water rates will have to go up if the water works industry is to supply the demands upon it. This state of affairs now exists in many towns in other size classifications, and it is only a matter of time before the 4–11 per cent annual increase in water consumption makes the condition universal. Every water works not now impounding its surplus should plan to do so and devise a rate structure to supply cash for future construction, if at all possible.

Most water works have never experienced such prosperity as they enjoy today. They are supplying so much more water with their original investment that, even with increased operating expenses, their cost per 1,000 gal. pumped has decreased. Nevertheless, the water operator must realize that there is a limit to the capacity of his plant and its durability and that certain portions are becoming obsolete according to steadily advancing stand-

ards of water purification. It will suddenly be discovered that new loads cannot be continually added at the low cost of the last few years and that a major operation of expansion will be necessary at prices in no way similar to those paid for the old plant. Then the cost per 1,000 gal. pumped with the expanded plant will be so much higher than at present that the current surplus and existing water rate structure will seem small in comparison.

Impounding of Surplus

Though it may not exactly be a problem for water works management to rectify, if such works ever expect to build up the urgently needed surplus for normal expansion of facilities, they must attack the problem of the diversion of surplus funds to the city treasury. Many works would not be in "hot water" today if they had impounded their surplus over the last ten years and could finance needed improvements with cash instead of paying about 25¢ for every dollar borrowed. Municipal governments have faced a problem of ever increasing costs in administration, street maintenance, refuse collection and disposal, and police and fire protection, with seemingly no additional taxing power to obtain the needed revenue. They have felt forced to dip into the water works funds to maintain their services at a minimum level, thus jeopardizing the future of those works.

All governmental subdivisions except the cities obtain a portion of the gasoline tax to support roads, yet the city streets carry the major portion of the traffic. To help them, state highway departments are taking over highways through cities, thereby making the cities' rights to the use of these streets for water and sewer lines subject to state control. An unreasonable highway commission could split a water or sewer system in two and even prevent its expansion or its construction in the first place.

Would it not be a just and practical solution for the states to authorize an additional gasoline tax to be apportioned to the cities for street maintenance and improvements, according to automobile registrations? Property taxes could then be used exclusively to support the governmental functions of administration and police and fire protection, as originally intended, and the water works and its customers would be relieved of the burden of partially financing these services. In the author's opinion, such a system would allocate the financial burdens where they rightfully belong.

TABLE 7

*Sewage Works Financing and Improvements for Small Towns**

Extensions and improvements surplus will carry at 2¼ per cent interest for 20 yr.	$8,400
Sewage works impounding surplus for future improvements—*per cent*	75
Sewage works needing improvements and expansion of treatment plant—*per cent*	50
Sewage works needing extensions to meet requests for service—*per cent*	75
Sewage works able to pay for above extensions out of surplus—*per cent*	25

* Kentucky towns of 1,000–4,000 population.

The cost of fire protection should be met by a property tax and not be borne by the water customers; thus, every city should pay a fire hydrant rental to cover the extra cost of water works for such service. The inauguration of such a charge at this time would do much to help water works meet their expansion obligations.

Sewage Works Financing

This paper has touched very little on sewage works financing problems. As such systems have just recently started on the path traversed by water works in the last 25 years, their problems should be similar except with regard to the incentive of towns to build works and customers to pay for the service. The town or industry which receives water from the surrounding streams or underground pools for its own use should accept the responsibility of returning it to the streams in a normal raw water condition. In turn, the town should have as much right to shut off water for nonpayment of the sewer bill as for nonpayment of the water bill, to prevent the use of the sewer and treatment facilities without due compensation. Based on this right, sewage works financed by revenue bonds are proving successful.

Sewage works construction prices have risen more since 1938 than water works prices because of the greater amount of construction labor involved on the site of the work. In Kentucky and Tennessee, sewage works prices have increased approximately 130 per cent. Revenues from sewer service rates in many of the towns with populations between 1,000 and 4,000 were not sufficient to pay the total cost of the service in 1940, but the rapid increase in the use of the service since then caused it to become self-supporting by 1946. The total cost per customer and per 1,000 gal. treated now runs to about half that for water service, based on prewar investment. On the basis of postwar investment, both services should cost approximately the same. This will mean at least a 100 per cent increase in sewer service rates. Investment will be larger than for water works but operating costs will be lower.

The urgency of sewage works construction for reasons of health and nuisance abatement has mounted rapidly since 1940, but little has been done to meet the problem. Before large numbers of entirely new works can be built at postwar construction prices, either the citizens and industries of cities causing stream pollution will have to be educated to accept the responsibility for, and the cost of, sewage treatment, or stream pollution control must come to be considered a nationwide concern with the nation as beneficiary. If the paternalistic view is taken, federal aid would be in order.

Undoubtedly, from now on in most towns sewage service will be given the same utility status as water and will be supported by revenues proportional to the water consumed, the burden of sewer construction and maintenance being removed from the property tax payer. The joint operation of the water and sewage works should work to their mutual advantage in billing, collections, and use of crews and equipment; more competent management will be possible than under separate operation.

Conclusion

A considerable number of towns in Kentucky and Tennessee have increased water rates since the war by 33 to 50 per cent. Such raises were accepted with good grace by the public after it experienced a water shortage or was shown the need for rate increases. The situation must be explained to the public so that water systems can raise rates and expand, or be in financial condition to expand, before a water shortage occurs or service is impaired.

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **39**:473 (May '47) indicates volume 39, page 473, issue dated May 1947. If the publication is paged by the issue, **39**:5:1 (May '47) indicates volume 39, number 5, page 1, issue dated May 1947. Abbreviations following an abstract indicate that it was taken, by permission, from one of the following periodicals: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; Corr.—Corrosion; I.M.—Institute of Metals (British); P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British).*

HEALTH AND HYGIENE

Typhoid in the Large Cities of the United States in 1946. ANON. J. Am. Med. Assn. **134**:1086 (July 26, '47). Previous annual summaries reproduced in JOURNAL as follows: **20**:257; **21**:963; **22**:1122; **23**:1059; **24**:1066; **25**:1157; **26**:939; **27**:1593; **28**:1123; **29**:1177; **30**:1456; **31**:1561; **32**:1394; **34**:449; and **39**: 184. As in previous reports communication addressed to health officer of each city requesting number of deaths from typhoid, excluding paratyphoid, both among residents and among nonresidents as recorded for '46. Health directors of many cities keep no data on re-allocations for residence, and this information can be secured only from state health department, whose figures not available until several months after close of calendar year. Sometimes multiple inquiries brought forth irreconcilable replies. Too frequently reporting of deaths left to subordinate employees, and carelessness evident. Health officer should give final approval to statistical data released by his department. A few health officers seem to have no knowledge of how many typhoid deaths have occurred in their community, and it becomes increasing struggle to obtain accurate data. Possession of basic data seems paramount to establishment and operation of adequate local health service. For most cities of 100,000 pop. or more Census Bureau has no ests. of pop. for dates since '40. Figures for few cities based on special or sample censuses for various dates since '40. Special censuses conducted for Long Beach, Los Angeles, Oakland and San Diego in '46. Census Bureau has released pop. est. for Washington, D.C., as of July 1, '46. Sample censuses taken in '44 for Detroit, Norfolk, Portland, San Francisco, Seattle and Tacoma. (Special census taken in San Francisco in Aug. '45.) Ests. of civilian pop. of counties available for Mar. 1 and Nov. 1, '43, based on registrations for war ration books 2 and 4. Some cities (Baltimore, Denver, New Orleans, New York, Norfolk, Philadelphia, Richmond, St. Louis, San Francisco, Washington) coterminous with their counties and figures given in releases are city as well as county ests. Since for vast majority of cities no official figures available for any date subsequent to '40 federal census, again deemed advisable to employ pops. detd. by this uniform tabulation. For those cities for which special census figures available, corrections in rates shown in footnotes. Usually no, or only minor, changes in rates. No rate extended beyond first decimal point, and it is realized that this practice creates slight disadvantage for extremely large cities which now have but single death from typhoid (Detroit). Paratyphoid again excluded. Special note made of cities in which all deaths occurred in nonresidents. In addn. to 62 cities enumerated on honor roll in Table 1, 5 cities (Birmingham, Norfolk, Pittsburgh, St. Louis, Spokane) qualified for such acclaim but have been charged with typhoid deaths among nonresidents cared for in these cities. In 5 other cities (Houston, Knoxville, Los Angeles, New Orleans, Tacoma) more than ⅓ of reported deaths stated to have been among nonresidents. Noteworthy that for first time there is no city with death rate in excess of 2.0, and thus list of cities of second rank completely omitted. Number of cities with no typhoid death during past 2 or more years increased from 25 in '41 and 41 in '45 to new high of 49 in '46 (Table 2). Fort Wayne continues to head list with no death in 12 yr. Fall River and Lynn report no death in 10 yr., Cam-

TABLE 1

Typhoid Death Rates in 1946

Honor Roll: No Typhoid Deaths (62 Cities*)

Akron	El Paso	Lynn	Salt Lake City
Albany	Erie	Miami	San Diego
Atlanta	Evansville	Milwaukee	Seattle
Boston	Fall River	Minneapolis	Somerville
Bridgeport	Flint	Nashville	South Bend
Buffalo	Fort Wayne	Newark	Springfield
Canton	Gary	New Bedford	St. Paul
Cambridge	Grand Rapids	New Haven	Syracuse
Camden	Hartford	Oakland	Toledo
Charlotte	Indianapolis	Oklahoma City	Trenton
Chattanooga	Jacksonville	Paterson	Tulsa
Cleveland	Jersey City	Peoria	Waterbury
Columbus	Kansas City, Kan.	Providence	Wichita
Des Moines	Kansas City, Mo.	Reading	Worcester
Duluth	Long Beach	Richmond	Yonkers
Elizabeth	Lowell		

First Rank: From 0.1 to 1.9 Deaths per 100,000 (34 Cities†)

Baltimore	0.1	Rochester	0.3	Dallas	0.7
Chicago	0.1	San Francisco	0.3	Portland	0.7
Detroit	0.1	New Orleans	0.4§	Scranton	0.7
New York	0.1	Omaha	0.4	Spokane	0.8‡
Philadelphia	0.1	San Antonio	0.4	Sacramento	0.9
Pittsburgh	0.1‡	Dayton	0.5	Washington	0.9‖
St. Louis	0.1‡	Houston	0.5§	Wilmington	0.9
Cincinnati	0.2	Fort Worth	0.6	Utica	1.0
Denver	0.3	Louisville	0.6	Norfolk	1.4‡
Los Angeles	0.3†	Youngstown	0.6	Knoxville	1.8§
Memphis	0.3	Birmingham	0.7‡	Tacoma	1.8§
				Tampa	1.8

* 60 without Charlotte and Gary.
† 33 without Sacramento.
‡ All typhoid deaths stated to be in nonresidents.
§ Of typhoid deaths reported, ½ or more stated to be in nonresidents.
‖ 1946 special census gives rate of 0.7 for 1946 for Washington.

TABLE 2

Cities With No Typhoid Deaths in 1945–46
(49 Cities)*

City	Years†	City	Years†
Akron	2	Lowell	3
Albany	6	Lynn	10
Bridgeport	5	Milwaukee	3
Buffalo	2	Minneapolis	5
Canton	7	New Haven	3
Cambridge	9	Oakland	3
Charlotte	2	Oklahoma City	2
Chattanooga	5	Paterson	5
Cleveland	2	Peoria	3
Des Moines	7	Providence	2
Duluth	8	Reading	5
Elizabeth	2	Salt Lake City	5
El Paso	2	San Diego	4
Erie	7	Somerville	6
Evansville	6	South Bend	2
Fall River	10	Springfield	8
Flint	2	Syracuse	2
Fort Wayne	12	Toledo	3
Gary	6	Trenton	6
Grand Rapids	7	Tulsa	7
Hartford	8	Waterbury	3
Jersey City	4	Wichita	4
Kansas City, Kan.	3	Worcester	5
Kansas City, Mo.	2	Yonkers	8
Long Beach	3		

* 47 without Charlotte and Gary.
† Consecutive years with no typhoid deaths.

bridge no death in 9 yr. Hartford, Springfield and Yonkers have clear records for 8 yr. South Bend reports no typhoid death among residents for 11 yr. *New England cities* (Table 3) (pop. 2,579,152) have set new all-time record with no deaths from typhoid in '46. These cities reported lowest group rates in each of quinquennial periods (Table 4). East North Central cities, although reporting a new low rate (0.06), must now be content with second place. They were in first place in '45 (0.07). West North Central cities follow close behind (0.07) and nose out Middle Atlantic cities (0.11). Only Mountain and Pacific cities record higher death rate for '46 (0.31) than for '45 (0.17). Only 3 deaths in New England cities during past 3 yr.: 1 in Providence in '44, 1 each in Boston and New Bedford in '45. While in '40 ½ of 18 cities which recorded no deaths from typhoid during 2-yr. period were New England cities, in '46 only about ¼ (14 among 49) from this group. New England cities with perfect record can do no better, but tendency for other cities to attain high stds.

TABLE 3

Typhoid Death Rates per 100,000 Population of 96 Large Cities, by Geographic Divisions, 1906–46

City	1946	1945	1941–1945	1936–1940	1931–1935	1926–1930	1921–1925	1916–1920	1911–1915	1906–1910
New England States										
Cambridge	0.0	0.0	0.0	0.2*	0.8	2.1	4.3	2.5	4.0	9.8
Fall River	0.0	0.0	0.0	0.2	0.2	2.2	2.3	8.5	13.4	13.5
Lynn	0.0	0.0	0.0	0.2	0.2	1.5	1.6	3.9	7.2	14.1
Springfield	0.0	0.0	0.0	0.3*	1.1†	0.4	2.0	4.4	17.6	19.9
Hartford	0.0	0.0	0.0	0.5	1.0†	1.3	2.5	6.0	15.0	19.0
Somerville	0.0	0.0	0.0	0.6	0.4	1.3	1.6	2.8	7.9	12.1
Worcester	0.0	0.0	0.1	0.2*	0.5*	1.0	2.3	3.5	5.0	11.8
Bridgeport	0.0	0.0	0.1	0.4	0.3	0.5	2.2	4.8	5.0	10.3
Lowell	0.0	0.0	0.2	0.4	1.2	2.6	2.4	5.2	10.2	13.9
Providence	0.0	0.0	0.2†	0.6	1.1†	1.3	1.8	3.8	8.7	21.5
New Haven	0.0	0.0	0.2†	1.0	0.7†	0.6	4.4	6.8	18.2	30.8
Waterbury	0.0	0.0	0.8	0.2	0.4	1.2	1.0	8.0	18.8	
Boston	0.0	0.1	0.1	0.3†	0.6	1.2	2.2	2.5	9.0	16.0
New Bedford	0.0	0.9	0.2	0.4	1.1	1.5	1.7	6.0	15.0	16.1
Middle Atlantic States										
Yonkers	0.0	0.0	0.0	0.3	0.7	0.5	1.7	4.8	5.0	10.3
Erie	0.0	0.0	0.0	0.7†	1.2	0.9	2.3	6.9	49.0	46.6
Albany	0.0	0.0	0.0	1.2†	1.2	1.8	5.6	8.0	18.6	17.4
Trenton	0.0	0.0	0.0	1.4†	1.1	2.1	8.2	8.6	22.3	28.1
Jersey City	0.0	0.0	0.1†	0.6	0.3	0.9	2.7	4.5	7.2	12.6
Paterson	0.0	0.0	0.1*	0.7†	0.9	1.0	3.3	4.1	9.1	19.3
Buffalo	0.0	0.0	0.2	0.1	0.6	2.7	3.9	8.1	15.4	22.8
Reading	0.0	0.0	0.2	0.5	0.4	1.6	6.0	10.0	31.9	42.0
Syracuse	0.0	0.0	0.3†	0.3*	0.8	0.8	2.3	7.7	12.3	15.6
Elizabeth	0.0	0.0	0.4	0.5	0.9	1.6	2.4	3.3	8.0	16.6
Newark	0.0	0.5	0.1	0.3	0.4	0.9	2.3	3.3	6.8	14.6
Camden	0.0	1.7†	0.5†	1.4†	2.7	4.4	5.9	4.9	4.5	4.0
New York	0.1	0.1	0.1	0.3	0.8	1.3	2.6	3.2	8.0	13.5
Pittsburgh	0.1*	0.4	0.3	0.7	0.9	2.4	3.9	7.7	15.9	65.0
Philadelphia	0.1	0.6	0.3	0.8	0.9	1.1	2.2	4.9	11.2	41.7
Rochester	0.3	0.0	0.1	0.3†	0.4	1.7	2.1	2.9	9.6	12.8
Scranton	0.7	0.0	0.0	0.3	1.4	1.8	2.4	3.8	9.3	31.5
Utica	1.0	0.0	0.4†	0.2*	0.2	1.1	3.9‡			
South Atlantic States										
Charlotte	0.0	0.0	0.6†	1.6†	2.5					
Miami	0.0	0.6	0.6	2.4	2.0	3.5				
Jacksonville	0.0	0.6	0.8	2.3	1.6	4.4				
Atlanta	0.0	1.0†	0.5†	2.1†	7.3	11.1	14.5	14.2	31.4	58.4
Richmond	0.0	2.1†‖	1.3†‖	2.5†	2.4	1.9	5.7	9.7	15.7	34.0
Baltimore	0.1	0.2†	0.3†	0.9†	1.4	3.2	4.0	11.8	23.7	35.1
Washington	0.9§	0.3¶	0.4†¶	1.1	2.2	2.8	5.4	9.5	17.2	36.7
Wilmington	0.9	0.9*	0.2*	0.5	1.5	3.1	4.7	25.8‡	23.2‡	33.0
Norfolk	1.4*	0.7¶	0.3¶	1.1†	3.3	2.2	2.8	8.8	21.7	42.1
Tampa	1.8	1.8	1.8	0.6†	3.4	3.8	19.1	43.9‡		
East North Central States										
Fort Wayne	0.0	0.0	0.0	0.0	2.1	4.2	12.9	7.3		
Canton	0.0	0.0	0.0	0.4†	0.8	1.4	3.3	8.9		
Grand Rapids	0.0	0.0	0.0	0.5†	0.2	1.0	1.9	9.1	25.5	29.7
Gary	0.0	0.0	0.0	1.1	0.8					
Evansville	0.0	0.0	0.0	1.2†	1.8	6.2	5.0	17.5	32.0	35.0
Milwaukee	0.0	0.0	0.1	0.1	0.2	0.8	1.6	6.5	13.6	27.0
Akron	0.0	0.0	0.1*	0.6†	0.9	1.5	2.4	10.6	21.0	27.7‡
South Bend	0.0	0.0	0.2*	0.0	0.8					
Cleveland	0.0	0.0	0.2	0.6	1.1	1.0	2.0	4.0	10.0	15.7
Flint	0.0	0.0	0.2	1.3†	0.8	1.6	4.6	22.7	18.8	46.9
Peoria	0.0	0.0	0.6†	1.3†	0.9	0.2	3.7	5.7	16.4	15.7‡
Toledo	0.0	0.0	1.1	1.0†	1.2	3.0	5.8	10.6	31.4	37.5
Indianapolis	0.0	0.3*	0.3†	1.2†	1.8	2.7	4.6	10.3	20.5	30.4
Columbus	0.0	0.3*	0.4†	1.4†	1.9	2.1	3.5	7.1	15.8	40.0
Chicago	0.1	0.1	0.1	0.3	0.4	0.6	1.4	2.4	8.2	15.8
Detroit	0.1	0.1*	0.1	0.4	0.7	1.3	4.1	8.1	15.4	22.8
Cincinnati	0.2	0.4†	0.3†	1.1†	1.4	2.5	3.2	3.4	7.8	30.1
Dayton	0.5	0.5	0.3†	1.4	0.8	1.9	3.3	9.3	14.8	22.5
Youngstown	0.6	0.0	0.1*	0.7	1.2	1.1	7.2	19.2	29.5	35.1

TABLE 3—*Continued*

City	1946	1945	1941–1945	1936–1940	1931–1935	1926–1930	1921–1925	1916–1920	1911–1915	1906–1910
East South Central States										
Chattanooga	0.0	0.0	0.2	0.9	5.8	8.0	18.6	27.2	35.8‡	
Nashville	0.0	0.6*	0.5*	3.4†	5.7	18.2	17.8	20.7	40.2	61.2
Memphis	0.3	0.0	0.3†	4.0†	7.5	9.3	18.9	27.7	42.5	35.3
Louisville	0.6	0.6†	0.5†	0.9	2.8	3.7	4.9	9.7	19.7	52.7
Birmingham	0.7*	1.9†	0.9†	2.5†	4.1	8.0	10.8	31.5	41.3	41.7
Knoxville	1.8†	0.9*	1.2*	3.8	6.0	10.7	20.8	25.3‡		
West North Central States										
Duluth	0.0	0.0	0.0	0.2	1.0	1.1	1.7	4.4	19.8	45.5
Des Moines	0.0	0.0	0.0	1.3	2.5	2.4	2.2	6.4	15.9	23.7
Minneapolis	0.0	0.0	0.1	0.2	0.8	0.8	1.9	5.0	10.6	32.1
Kansas City, Mo.	0.0	0.0	0.1†	0.9†	1.6	2.8	5.7	10.6	16.2	35.6
Wichita	0.0	0.0	0.2	0.4	1.1	1.2	6.3			
Kansas City, Kan.	0.0	0.0	0.8†	1.0	1.0	1.7	5.0	9.4	31.1	74.5‡
St. Paul	0.0	0.3	0.1	0.3	0.7	1.4	3.4	3.1	9.2	12.8
St. Louis	0.1*	0.1	0.2†	0.7	1.6	2.1	3.9	6.5	12.1	14.7
Omaha	0.4	0.4	0.1	0.6	0.9	1.3	3.3	5.7	14.9	40.7
West South Central States										
Tulsa	0.0	0.0	0.0	0.4	1.1	8.3	16.2‡			
Oklahoma City	0.0	0.0	0.1	2.6	4.3	7.4‡				
El Paso	0.0	0.0	2.7	4.5	5.2	9.1	10.8	30.7	42.8	
San Antonio	0.4	0.4	0.3	2.9	4.3	4.6	9.3	23.3	29.5	35.9
New Orleans	0.4†	1.2**	1.4†	5.0†	9.6	9.9	11.6	17.5	20.9	35.6
Houston	0.5†	0.8†	1.1	2.3	3.2	4.8	7.6	14.2	38.1	49.5‡
Fort Worth	0.6	0.6	0.4†	2.1	4.5	5.9	6.1	16.3‡	11.9	27.8
Dallas	0.7	0.3	0.9†	2.7†	5.1	7.3	11.2	17.2		
Mountain and Pacific States										
Salt Lake City	0.0	0.0	0.1*	0.3*	0.7	1.9	6.0	9.3	13.2	41.1
Long Beach	0.0	0.0	0.1	0.5	0.5	1.1	2.1‡			
Oakland	0.0	0.0	0.2	0.5†	1.2	1.2	2.0	3.8	8.7	21.5
San Diego	0.0	0.0	0.2†‡‡	0.8	1.3	1.0	1.6	7.9	17.0	10.8
Seattle	0.0	0.3	0.1	0.2	0.7	2.2	2.6	2.9	5.7	25.2
Denver	0.3	0.0	0.3†	1.4	1.7	2.6	5.1	5.8	12.0	37.5
San Francisco	0.3	0.2*††	0.1†	0.4	0.8	2.0	2.8	4.6	13.6	26.3
Los Angeles	0.3†	0.3	0.3	0.7†	0.8	1.5	3.0	3.6	10.7	19.0
Portland	0.7	0.0	0.1*	0.3	0.8	2.3	3.5	4.5	10.8	23.2
Spokane	0.8*	0.0	0.6†	1.2	1.0	2.2	4.4	4.9	17.1	50.3
Sacramento	0.9	0.9	0.4†	1.5*	6.3					
Tacoma	1.8†	0.0	0.5†	0.5	0.9	1.8	3.7	2.9	10.4	19.0

* All typhoid deaths stated to be in nonresidents.
† One-third or more of reported typhoid deaths stated to be in nonresidents.
‡ Incomplete data.
§ 1946 special census gives rate of 0.7 for 1946 for Washington.
‖ 1943 special census gives rate of 1.8 for 1945 and 1.2 for 1941–45 for Richmond.
¶ 1944 special census gives rate of 0.2 for 1945 and 0.3 for 1941–45 for Washington, and rate of 0.4 for 1945 and 0.2 for 1941–45 for Norfolk.
** All typhoid deaths stated to be in nonresidents. 1943 special census gives rate of 1.1 for 1945 and 1.3 for 1941–45 for New Orleans.
†† 1945 special census gives rate of 0.1 for 1945 for San Francisco.
‡‡ 1944 special census gives rate of 0.1 for 1941–45 for San Diego.

set by this group. 12 large *Middle Atlantic cities* (pop. 13,129,185) (13 in '45) report no death from typhoid in '46. Albany, Buffalo, Elizabeth, Erie, Jersey City, Paterson, Reading, Syracuse, Trenton and Yonkers maintd. '45 ranking while Camden and Newark have been added to honor roll. Rochester and Scranton, each with 1 death in '46, elimd. from honor roll, Scranton after 6 yr. with no death. Middle Atlantic cities have group rate (0.11) only slightly higher than that of East North Central and West North Central cities. Much lower than rate for '45 (0.23) but not as low as for '43 (0.08). In '46, 14 deaths, 13 among residents; in '45, 30 deaths, 25 among residents; in '43, 11 deaths, 9 among residents. Jersey City reports no typhoid death for 4 yr. (Table 2), Paterson

and Reading none for 5 yr., Albany and Trenton none for 6, Erie none for 7, Yonkers none for 8 yr. Utica records 1 death among residents in '46, second such death in 15 yr. Stated that although death occurred in resident of Utica, source of infection reliably established as being in Italy. New York records 8 deaths, in '46, all among residents (11 in '45, 13 in '44). Low mark reached in New York in '43 with 4 deaths, 3 among residents. (In '42, 5, all among residents.) New York reports localized outbreak with 20 cases and no deaths in August '46; outbreak attributed to fresh vegetables contamd. by sewage backed up out of toilet bowl in apartment immediately over vegetable store. Stated that in Philadelphia there occurred 2 deaths, both among residents. This marks new low for city. Pittsburgh records but 1 death, which occurred in a nonresident. Pittsburgh reported no death among residents death. *East North Central cities* (pop. 9,386,378) lost first place, which they held in '45 and back in '41 and '38. 14 (13 exclusive of Gary) of cities in this group (Akron, Canton, Cleveland, Columbus, Evansville, Flint, Fort Wayne, Gary, Grand Rapids, Indianapolis, Milwaukee, Peoria, South Bend, Toledo) report no death from typhoid in '46. Gary added to this group in '40, but figures for this city omitted in detg. rates for whole group. Number of typhoid deaths decreased from 7 in '45 (33 in '40, 13 in '44) to 6 in '46, new low (rate from 0.35 in '40, 0.14 in '44 and 0.07 in '45 to 0.06 in '46). 12 cities (Akron, Canton, Cleveland, Evansville, Flint, Fort Wayne, Gary, Grand Rapids, Milwaukee, Peoria, South Bend, Toledo) record no typhoid death during '45 and '46 (Table 2), Fort Wayne none for 12 yr. (longest honor record of any city), Canton and Grand Rapids none for 7, Evansville and Gary none for 6 yr.

TABLE 4

Total Typhoid Death Rate per 100,000 Population of 93 Cities, by Geographic Divisions, 1931–46

Area	Population*	Typhoid Deaths		Typhoid Death Rates				
		1946	1945	1946	1945	1941–1945	1936–1940	1931–1935
New England	2,579,152	0	2	0.00	0.08	0.14	0.39	0.70
Middle Atlantic	13,129,185	14	30	0.11	0.23	0.17	0.43	0.80
South Atlantic	2,727,985	12	17	0.44	0.62	0.54	1.14	2.70
East North Central	9,386,378	6	7	0.06	0.07	0.16	0.53	0.75
East South Central	1,286,747	7	9	0.54	0.70	0.57	2.54	4.81
West North Central	2,716,484	2	3	0.07	0.11	0.16	0.60	1.24
West South Central	2,048,692	8	12	0.39	0.59	0.89	3.09	5.36
Mountain and Pacific	4,186,039	13	7	0.31	0.17	0.23	0.60	0.88

* 1940 census figures used.

in '42 and again in '46. Rate (0.44) for *South Atlantic cities* (pop. 2,727,985) twice low rate for '44 (0.22) but significantly lower than rate for '45 (0.62). In these cities 12 deaths in '46 (9 among residents), 17 in '45 (11 among residents), 6 in '44 (3 among residents). 5 cities (Atlanta, Charlotte, Jacksonville, Miami, Richmond) on honor roll; stated that 2 deaths in Norfolk occurred among nonresidents. In '45 Charlotte only city on honor roll. In '44 6 such cities (Atlanta, Jacksonville, Miami, Norfolk, Tampa, Wilmington). Charlotte included in group for fifth time; however, for purposes of adequate comparison figures for this city omitted in calcg. rates for whole group. Washington records 6 deaths in '46, 5 among residents (2 deaths in '45, 4 in '44, 1 in '43). Tampa reports 2 deaths, both among residents, Baltimore and Wilmington each 1 such Chicago records 2 deaths and Cincinnati, Dayton, Detroit and Youngstown each 1 death, all among residents. Detroit reports that among 24 cases of typhoid attributed to church supper in near-by community, 13 in residents of Detroit among whom no deaths. Person prepg. and serving food found to be typhoid carrier. *East South Central cities* group (pop. 1,286,747) shows decrease in death rate (0.54 in '46, 0.70 in '45). However, lower death rate (0.31) recorded in '44 and same rate in '42 (0.54). This group has highest group rate for '46, position it also held in '45, South Atlantic cities being next (0.44). Effect of hospitalizing patients from surrounding rural areas continues to be evident. Of 7 deaths in '46, 4 among nonresidents (7 of 9 deaths in '45). 2 cities (Chattanooga and Nashville) report no deaths among either residents or nonresidents and

appear on honor roll. 2 deaths in Birmingham and 1 death in Memphis stated to be among nonresidents. Chattanooga reports no death for 5 yr. (Table 2). Knoxville records 2 deaths, 1 among residents; Louisville 2 deaths, both among residents. *West North Central cities* (pop. 2,716,484) show decrease in number of deaths from 3 to 2; 1 of 2 among residents. Death rate declined from 0.11 in '45 (same in '43 and '44) to 0.07 in '46. 7 cities (Des Moines, Duluth, Kansas City (Kan.), Kansas City (Mo.), Minneapolis, St. Paul, Wichita) record no death, and St. Louis reports 1 death among nonresidents. After period of 4 yr. ('41–'44) without death, Omaha reported 1 death in '45 and another in '46. No typhoid death in Duluth for past

TABLE 5

Number of Cities With Various Typhoid Death Rat

	No. of Cities	10.0 and Over	5.0 to 9.9	2.0 to 4.9	1.0 to 1.9	0.1 to 0.9	0.0
1906–1910	77	75	2	0	0	0	0
1911–1915	79	58	19	2	0	0	0
1916–1920	84	22	32	30	0	0	0
1921–1925	89	12	17	48	12	0	0
1926–1930	92	3	10	30	37	12	0
1931–1935	93	0	6	17	28	42	0
1930......	93	2	6	30	23	22	10
1931......	93	2	6	23	28	22	12
1932......	93	1	7	13	29	29	14
1933......	93	0	7	18	19	33	16
1934......	93	0	9	11	27	23	23
1935......	93	0	7	15	18	29	24
1936......	93	0	3	15	21	36	18
1937......	93	0	1	13	26	26	27
1938......	93	0	3	13	14	34	29
1939......	93	0	3	7	17	32	34
1940*.....	93	0	0	12	12	30	39
1941*.....	93	0	0	4	7	46	36
1942*.....	93	0	1	3	5	34	50
1945*.....	93	0	0	1	5	31	56
1946*.....	93	0	0	0	5	28	60

* Charlotte, Gary and Sacramento omitted.

8 yr. (Table 2), none in Des Moines for 7, none in Minneapolis for 5, none in Wichita for 4 yr. Kansas City, Mo., records no death among residents for 5 yr. 8 *West South Central cities* (pop. 2,048,692) report continued reduction in death rate (2.00 in '40, 0.83 in '43, 0.59 in '45, 0.39 in '46). Actual number of deaths decreased from 12 in '45 (41 in '40) to 8 in '46, lowest on record. Of 8 deaths in this group of cities, 2 among nonresidents (8 of 12 in '45). Low point for deaths among residents (4) occurred in '45. 3 cities (El Paso, Oklahoma City, Tulsa) record no death in '46. Tulsa reports no death for 7 yr. Dallas reports 2 deaths among residents. Stated that of 2 deaths

TABLE 6

Total Typhoid Death Rates

Year	Population	Typhoid Deaths	Typhoid Death Rate per 100,000
Total of 78 Cities, 1910–46*			
1910......	22,573,435	4,637	20.54
1911......	23,211,341	3,950	17.02
1912......	23,835,399	3,132	13.14
1913......	24,457,989	3,285	13.43
1914......	25,091,112	2,781	11.08
1915......	25,713,346	2,434	9.47
1916......	26,257,550	2,191	8.34
1917......	26,865,408	2,016	7.50
1918......	27,086,696†	1,824†	6.73
1919......	27,735,083†	1,151†	4.15
1920......	28,244,878	1,088	3.85
1921......	28,859,062	1,141	3.95
1922......	29,473,246	963	3.26
1923......	30,087,430	950	3.16
1924......	30,701,614	943	3.07
1925......	31,315,598	1,079	3.44
1926......	31,929,782	907	2.84
1927......	32,543,966	648	1.99
1928......	33,158,150	628	1.89
1929......	33,772,334	537	1.59
1930......	34,410,235	554	1.61
1931......	34,508,750	563	1.63
1932......	34,607,505	442	1.28
1933......	34,708,945	423	1.22
1934......	34,833,650	413	1.19
1935......	35,005,351	348	0.99
1936......	35,196,325	337	0.96
1937......	35,386,380	289	0.82
1938......	35,578,011	257	0.72
1939......	35,767,022	232	0.65
1940......	35,895,638	172	0.48
1941......	35,895,638‡	123	0.34
1942......	35,895,638‡	83	0.23
1943......	35,895,638‡	78	0.22
1944......	35,895,638‡	66	0.18
1945......	35,895,638‡	80	0.22
1946......	35,895,638‡	54	0.15
Total of 93 Cities, 1935–46			
1935......	37,025,179	385	1.04
1936......	37,241,414	366	0.98
1937......	37,459,339	324	0.86
1938......	37,680,155	298	0.79
1939......	37,900,354	259	0.68
1940......	38,060,662	190	0.50
1941......	38,060,662‡	141	0.37
1942......	38,060,662‡	95	0.25
1943......	38,060,662‡	85	0.22
1944......	38,060,662‡	73	0.19
1945......	38,060,662‡	87	0.23
1946......	38,060,662‡	62	0.16

* Following 15 cities omitted from this table because data for full period not available: Canton, Chattanooga, Dallas, Fort Wayne, Jacksonville, Knoxville, Long Beach, Miami, Oklahoma City, South Bend, Tampa, Tulsa, Utica, Wichita, Wilmington.
† Data for Forth Worth lacking.
‡ 1940 census figures used.

each in Houston and New Orleans, 1 each among nonresidents. Fort Worth and San Antonio record 1 death each among residents. Noteworthy reduction in death rate of cities of this group from 5.36 for quinquennial

period '31–'35 to new low of 0.39 in '46. 11 *Mountain and Pacific cities* (excluding Sacramento) (pop. 4,186,039) report increase from 7 deaths in '45 to 13 in '46 (5 deaths in '44). Rate increased from 0.17 to 0.31 (0.12 in '44). This only group of cities which records more deaths from typhoid in '46 than in '45. Sacramento, again omitted in calcg. total number of deaths and rates, reports 1 death among residents. 5 of Mountain and Pacific cities (Long Beach, Oakland, Salt Lake City, San Diego, Seattle) report no death from typhoid in '46. 9 cities on honor roll in '44, 8 in '45. Long Beach, Oakland, Salt Lake City and San Diego maintd. ranking of '45. Salt Lake City reports no death during past 5 yr., San Diego none for 4 yr. Stated that 1 death in Spokane in a nonresident. Of 5 deaths in Los Angeles, 4 among residents. San Francisco and Tacoma each report 2 deaths, 1 in a nonresident. Denver records 1 death in a resident. Number of cities with no death from typhoid increased from 56 to 60 (Table 5). Charlotte and Gary, not included in group of 93 cities, also report no death. This by far best showing, and no city with rate of 2.0 or more. Number of cities with rates of less than 1.0 increased by 1 (88 in '46). 47 cities (49 with Charlotte and Gary) record no typhoid death in '45 and '46 (Table 2). Again emphasized that 5 cities (Birmingham, Norfolk, Pittsburgh, St. Louis, Spokane) in first rank would appear in honor roll if not charged with deaths among nonresidents. For 78 cities (Table 6) for which data available since '10, 54 deaths from typhoid in '46 (80 in '45, 66 in '44 and 78 in '43). This provides new low with rate of 0.15 (previous low 0.18 in '44). For all 93 cities number of deaths in '46 is 62 (87 in '45 and 73 in '44). Table 4 shows number of deaths for each of past 2 yr. in each group of cities. Also shows rates for '45 and '46 and for quinquennium '41–'45 and 2 preceding 5-yr. periods. It is hoped that New England cities will continue to hold unique record with no deaths and that other cities will soon find themselves in same class. Continued reduction in rates for all groups most impressive. For '46 health officers report only few localized typhoid outbreaks. Improvement general throughout country, and typhoid as cause of death in these cities fast approaching vanishing point. War years do not appear to have contributed materially to typhoid problem in large cities.—*Ed.*

The Role of Water in the Etiology of Poliomyelitis. RALPH R. SCOBEY. Arch. Pediat. **63**:567 (Nov. '46). Author points to evidence of severe epidemics of poliomyelitis during years of severe droughts and to periodicity of 15 yr. for both phenomena. Severe droughts and epidemics both occurred in '30 and '46. Disease also prevalent during dry season of year. Cyanide may be produced as result of decompn. of cyanophore glucosides from vegetable matter. Sulfocyanate may be present in animal excretions which can be converted to cyanide by oxidizing agents. Cyanides may also be produced as result of putrefaction of animal tissue. Cyanides produced from these sources may be washed from soil into ground or surface waters and may be augmented by cyanides produced from same sources in surface waters. Hydrocyanic acid may be present in water in sufficient quants. to produce poliomyelitis and other illnesses such as gastro-intestinal disturbances and rickets. High incidence of poliomyelitis may occur during droughts in certain parts of the country and with excessive pptn. in other districts. Cyanide poisoning can cause gastro-intestinal disturbances and neurological symptoms identical with those of poliomyelitis. Under conditions of drought, and consequent high cyanide content of water, gastro-intestinal disturbances and epidemic poliomyelitis would not be separate entities but conditions arising from same source. Foods harvested in advance of their natural maturity contain greater quant. of glucosides capable of producing hydrocyanic acid than those permitted to reach natural maturity. Drought would also increase hydrocyanic acid-producing glucosides in foods. Patients treated with sulfocyanates show toxic effects.—*Ed.*

Paralytic Shellfish Disease and Poliomyelitis. RALPH R. SCOBEY. Arch. Pediat. **64**:350 (July '47). There are many mysteries and anomalies regarding poliomyelitis which have not been adequately explained on basis of virus infection. Author does not deny that virus obtained from excreta or sewage will produce disease in animals, which author calls pseudopoliomyelitis, but no proof can be found that human being develops disease as result of infection by same virus. When one disregards virus theory of poliomyelitis, then clearer understanding results, and according to author observed facts regarding disease fit in better on basis of non-virus character of

causative agent. Paralytic shellfish (mussel poisoning) disease is acute poisoning with profound action on nervous system. First extensive epidemic of this disease in U.S. occurred in California in '27. In same year occurred greatest number of poliomyelitis cases in that state. Paralytic shellfish disease has been observed with greatest frequency in proximity of mouths of rivers entering Pacific Ocean. It occurs in summer months, similar to poliomyelitis. Symptoms of paralytic shellfish disease are 3 types: (1) gastro-intestinal type, (2) nervous or allergic type, and (3) paralytic type, which is fatal form. Cooked mussels just as potent as raw ones. This disease shows striking similarity to symptoms of poliomyelitis. Poisonous property not inherent in mussels but originates from food eaten by them. Poisonous mussels have in their stomach contents certain plankton organisms which are either not found or are present in very small amts. in stomachs of nontoxic mussels. Poison in plankton identical with poison in mussels. Fresh-water plankton, especially blue-green algae, definitely linked to several intoxications in animals. Thus algae in addn. to imparting tastes to water may be important in production of acute gastro-enteritis. Author compares distr. of '27 California (San Francisco area) cases of poliomyelitis and paralytic shellfish disease and finds close relationship. Observed that shellfish in Pacific Ocean accidentally poisoned by poisonous plankton that were in turn poisoned by substances originating in watershed areas involved. Existence of extensive epidemics of poliomyelitis and of paralytic shelfish disease at same time probably not coincidence but rather same etiological factor—hydrocyanic acid—responsible for each of these diseases. Hydrocyanic acid can be absorbed through skin and therefore bathers and waders in pold. water can absorb enough cyanide to produce this disease. Nervous or allergic type of paralytic shellfish disease has no resemblance to symptoms of poliomyelitis. But poliomyelitis is not one disease but rather group of diseases produced by common etiological factor—hydrocyanic acid. Many fruits contg. cyanophore glucosides produce allergic manifestations.—*Ed.*

Contribution to the Study of Methods of Indirect Spread of Poliomyelitis in Cuyo. J. S. Maurin Navarro & R. Bilella. Rev. Asoc. Med. Argentina (Arg.) **61**:601/602:195 (Mar. 15–30, '47). Two outbreaks of poliomyelitis in Cuyo dist. of Argentina in '43 to '44 studied with regard to distr. of cases in relation to rivers and watercourses. Outbreaks occurred in provinces of Mendoza and San Juan, and small-scale maps reproduced which show that all cases occurred near watercourses. Large-scale maps of Mendoza given, which show distr. of cases in relation to particular drainage canal; blocks of houses in which cases (16) occurred situated either next to canal (9 cases) or not more than 3 blocks away (6 cases). Canal in very unsanitary condition and heavily contamd. with refuse and human feces. Children in habit of using banks of canal as playground and ran obvious risk of being infected with virus. Similar state of affairs found in province of San Juan, where 27 cases occurred.—*B.H.*

Isolation of Morgan's Bacillus From Saline Waters. (Possibility of Water-borne Human Infection.) René Buttiaux & Jeannine Miege. Ann. Inst. Pasteur (Fr.) **73**:4:364 (Apr. '47). Authors successfully isolated Morgan's bacillus, type No. 1, (*Proteus morgani*) from flooded area in region of Dunkirk, where water strongly saline, between 9400 and 14,000 ppm. of sodium chloride detd. as chlorine. Technique was to conc. bacteria from large vol. of water by means of aluminium hydroxide, and to inoculate ppt. on solid and liquid media specially designed for isolation of intestinal pathogens. Morgan's bacillus found to be abundant and isolated from same sample points on several occasions. Also associated with *Proteus vulgaris* but no bacteriophage could be found for either organism. Antiserum, prepd. against one of strains isolated, agglutinated to equivalent titer all other strains obtained and it is suggested that there is common origin for these strains, and that these observations furnish evidence that human infection caused by this organism could be water-borne.—*B.H.*

Fluorine in United States Water Supplies—Pilot Project for the Atlas of Diseases. Anastasia Van Burkalow. The Geographical Review. 36:2:177 (Apr. '46). American Geographic Society of New York has collected from state agencies data as to fluorine content of natural waters in U.S. as first project for "atlas of diseases." Results of 12,000 anals. have been used to prepare maps indicating areas from which data assembled and also to show countries in which waters having max. fluorine content were found in

following ranges: 0–0.4 ppm.; 0.5–0.9 ppm.; 1.0–1.4 ppm. and 1.5 ppm. or more. Specific information lacking to enable more detailed mapping of ground waters as to fluorine content. Future studies will correlate the fluorine content of ground waters with geological data. Prelim. study has disclosed absence of extensive data as to fluorine content of rocks and natural waters. Estd. that 0.27% of earth's crust consists of fluorine. High fluorine content associated with prior volcanic action. Very few sedimentary rocks have been examd. for fluorine content but concluded that fluorine originated through weathering of igneous rocks and through washing of fluorine from volcanic gases in atm. Affinity between phosphates and fluorine considered as one chem. means by which fluorine tends to accumulate in areas where phosphate rocks have been deposited, which deposition associated with volcanic activity. Relative abundance of fluorine in rocks, as compared to ground waters, due to insol. nature of fluorine compds. Sulfuric acid formed by decompn. of pyrite is credited with dissolving fluorine compds. causing presence of fluorine in associated ground waters. Further study to be made of this relationship. Low rainfall in desert areas held responsible for observed higher fluorine content of ground waters in such areas, because of restricted amt. of leaching by limited ground water flow. This situation also may acct. for higher concn. of fluorine in shallow ground waters in desert areas as contrasted to fact that fluorine-bearing waters in other parts of country having more ample rainfall occur at greater depth. This study will serve as basis for appraisal of incidence of dental caries associated with potable water contg. less than 0.5 ppm. fluorine; incidence of mottled enamel of teeth associated with drinking waters contg. more than about 2.0 ppm. fluorine; and geographical factors governing distr. of fluorine-bearing waters.—*C. R. Cox.*

Fluorinated Water—Some Dental Factors. ANON. Am. City **63**:3:110 (Mar. '48). Beneficial effects of fluorine in water have been established. Resistance to tooth decay continues through life when caused by using fluorinated water during childhood. Persons over 40 yr. of age avg. 21 teeth decayed, missing or filled. Same age group which used fluoride water as children avgs. only 6 teeth decayed, missing or filled. No. of missing teeth 12 times greater in former group. Presumptive evidence indicates same results ca[n] be expected when water supplies artificially fluorinated. If proved in present demonstrations, a city such as Rapid City, S.D., would spend $2100 per yr. for fluorination, which would have saved $72,000 per yr. for dental work if Rapid City water contained sufficient fluorides 35 yr. ago.—*F. J. Maier.*

Lead in Drinking Water and Its Hygienic Importance. BORGOLTE. Öffentl. Gesundheitsdienst. (Ger.) **10**:9/10:A.110 (May '44). In Leipzig, in '30, Kruse recorded 250 cases of lead poisoning from drinking water. Poisonous concns. of lead in drinking water usually due to action of "lead-aggressive" water—i.e., with oxygen content above 6 mg./l., carbonate hardness less than 7° and pH value below 7—on household lead pipes. Lead content of such water may exceed "normal" limit of 0.3 mg./l. Only sign of lead absorption in areas where these conditions obtain may be presence of punctate basophilia. Author examd. 187 school children in small area of 2000 inhabitants where water known to be "lead aggressive" and estd. lead content of water from pipes of school at standing intervals of 1, 2, 3 and 14 hr., level rising from 1 mg./l. at 1 hr. to 5.0 at 14 hr. Blood examns. of children showed punctate basophilia below 300 per million in 90, and above this level in 97—39 of these were below 100[0] and 14 above 3000 per million. No difference in sex incidence noted, but gradual increase up to 5 yr. of school attendance with drop in 6th year. No clinical symptoms or signs of lead poisoning present, and group of children classed as below avg. in nutrition and general condition showed no higher degree of punctate basophilia than those classed as avg. and above avg. Author nevertheless considers his results demonstrate danger of lead poisoning from drinking water, especially in children, since possible later effects of const. slight lead absorption at present unknown. Author recommends that lead pipes should never be installed in areas where water "lead aggressive"; where this is not feasible, filter of "magnomasse" (magnesium hydroxide) should be used; and inhabitants should be warned not to drink water which has been standing all night in pipes.—*B.H.*

Health Hazards in Water Distribution Systems. HERMAN G. BAITY & EMIL T. CHANLETT. J. Inter-American Assn. Sanit. Eng. **1**:115 (Oct. '47). Effort and expen[se]

occurred protecting sources and treating water to insure freedom from contamn. with pathogens is lost if distr. system improperly protected against possibility of recontamination. Distr. system defects summarized as follows: uncovered tanks, reservoirs, or open conduits; system shutdowns; direct pumping from mains; improper installation and maint. of dual systems; cross-connections between potable water supplies and sewer lines or old. surface waters; back-siphonage. Defects explained, water-born-epidemics caused by them cited and preventive measures to avoid repetition of such disasters indicated.—*J. M. Sanchis.*

On the Question of the Hygienic Protection of Water Supplies in Cities and in the Country. HAYO BRUNS. Gas, Wasser, Wärme (Ger.) **1**:17 ('47). Towards end of war there occurred increase in typhoid and other water-borne diseases. Many of these may have been due to poverty and overcrowding by refugees from east, but often may have been due to lack of trained personnel. Water supt. primarily responsible for hygienic protection, and he can be punished by courts for neglect, but he can also require technical help of experts in many fields, as he himself cannot be specialist in all phases confronting him. Experts should investigate water problem as to source, treatment and distr. and should not be satisfied with few bact. tests. Tests should be judged critically and cautiously. Chemical anal. no longer given sanitary signif. that it had years ago. Even bact. test only biol. expt. and depends much on technique. Bad result chiefly indication of unfavorable conditions, and these should be located rather than condemn whole plant. Separation of different coliforms not justified. Lab. tests should always follow and supplement local inspection. Typhoid bacteria can seldom be found in water; for paratyphoid and cholera organisms conditions more favorable. Sources of infection can also come from back-siphoning and breaks in water lines. Chlorination should be considered as last recourse; uninterrupted chlorination has many disadvantages and liable to reduce attention given to treatment. Improvements of conditions in small communities and on farms more difficult to attain. Courses on public health in agricultural schools and for well drillers can help greatly. Regulations proposed to make bldg. permits depend on previously approved sanitary water source.—*Max Suter.*

FILTRATION

The Reclamation and Cleaning of Filters in Water Filtration Plants. G. H. STRICKLAND. Eng. Cont. Rec. (Can.) **60**:3:78 (Mar. '47). Following backwash schedule found most effective in Windsor, Ont.: 1st min., valve cracked and opened ¼; 2nd to 5th min., 50% max. flow (10″ rise) to permit scrubbing action between sand grains; 6th to final min., 20″ rise; final min., valve closed slowly to effect grading of sand. Avg. turbidity of wash water at end of backwash 15 ppm. Coating on sand grains results in loss during washing. Coating indicated by sp.gr. Following values found in Windsor. Clean sand, 2.65; below 6″ depth, 2.64–2.65, decreasing to 2.59–2.61 in top 2″; sand carried away during backwash, 2.58–2.59. Scrubbing action for 4 min. during backwash aids in controlling accumulation. Coating can be removed by 1 or more treatments with NaOH. Lower water to 6″ below sand surface, sprinkle flake NaOH over surface, 75 lb./100 sq. ft., admit water through underdrains to depth of 1″ above sand, allow to stand 96 hr., backwash, apply high-pressure water jet, and re-backwash. Rebuilding of Windsor's 10 filter beds necessary to correct uneven backwash, cement-bonded gravel layer having disintegrated. Underdrains consist of c-i. grid with 2.5″ laterals to 10 × 20″ manifold; brass orifices, ⅜″ diam., being spaced 7″ center-to-center; and filter bed of 8″ layer 2¾″ stone, 6″ layer 2½″ stone (cemented), layer of torpedo sand, and 36″ sand, E.S. 0.45 mm., and U.C. 1.2. Walls erected in filters and sand shifted to one side while overhauling other. New stone purchased in 5 sizes, 2″, 1″, ¾″, ⅜″ and torpedo, less than 60% of old gravel being recoverable and cost of reconditioning excessive. Less than 6 of 2016 orifices per filter found clogged and umbrella strainers required only light wire brushing. New gravel mat 18″ deep, uncemented, placed with great care. Work provided opportunity for acquainting operators with constr. and function of filter parts.—*R. E. Thompson.*

Comparative Data on Development of Algae in Covered and Uncovered Filters. ANON. Rev. Obras Sanit. Nacion (Arg.) **21**:85 (Sept.

'47). Study to det. effect of algae growths in rapid sand filters on water qual. in order to ascertain advisability of cover over filters indicated that algae developed in uncovered filters only; chlorophyceae found were *Ankistrodesmus* and *Cosmarium*; growth noticeable after 18–30 days in filters scrubbed with water and after 47–60 days in those whitewashed after scrubbing; organisms developed on walls and channels but did not go through filters nor affect qual. of filtered water. Water carried 0.3–0.4 ppm. residual chlorine as result of prechlorination, indicating chlorine tolerance of chlorophyceae found. Growths best controlled by scrubbing and whitewashing walls and channels with lime soln. contg. $CuSO_4$ every 60 days during months of greater solar illumination.—*J. M. Sanchis.*

English Practice in Hydraulic Controls for Water Purification Plant. DAVID BROWNLIE. Wtr. & Sew. (Can.) **85**:3:25 (Mar. '47). Lockheed hydraulic control, used for motor car brakes, adapted for operation of filter valves and other equip., notably at Southampton Otterbourne 3.5-mgd. plant. Battery of filters equipped with several cabinets, all served by 1 motor-driven pump delivering fluid at about 700-psi. pressure. If power fails, equip. easily operated manually at required speed of 120 strokes per min. Advantages include: (1) ease of installation, (2) small-diam. pipe, (3) min. maint., as hydraulic fluid self-lubricating, (4) fluid remains liq. to −40°C. Selector enables operation of desired valve, and opening and closing detd. by direction of rotation of pump.—*R. E. Thompson.*

A New Measure of the Filtrability of Fluids With Applications to Water Engineering. PERCIVAL LIONEL BOUCHER. J. Inst. Civ. Engrs. (Br.) **27**:4:415 (Feb. '47). Filtrability can be regarded as new phys. measurement of fluids as susceptible of definition as temp. Law referred to, "compound interest" law, expressed by familiar differential equation $dy/dx = ny$. In filtration, rate of increase of hydraulic resistance of filter with respect to vol. of fluid filtered, in certain conditions of operation, follows same law. Proposed filtration law refers to simple filtration. In applying to rapid or slow sand filtration some modification may be required where complex biol. processes complicate problem by changing nature of solids intercepted. Evidence, however, that rapid filtration can follow "compound interest" law. Straining is special case of filtration in which only problems of simple filtration have to be considered. Automatic strainers self-cleaning and work continuously, elimg. solids from liq. flowing through them, and disposing of these solids continuously. Term filtrability introduced by Sir Alexander Houston. In 17th Annual Report to Water Board he measured vol. of filtrate obtained in 1 min. from tap water passed through small linen filter which had previously filtered 100 ml. of water under examn. This vol. he later called "filtrability." For many practical problems of filtration and straining, possible to measure absolute index of filtrability. Tests show that if various vols. of water V are passed through filter under unvarying conditions, rate of increase of hydraulic resistance with respect to vol. filtered is proportional to hydraulic resistance H, or $dH/dV = nH$, whence $H = me^{nV}$, where m and n are constants. Filtrability index, denoted by I, may be written $I = \frac{1}{V} \log_e \left(\frac{H}{H_0}\right)$ where H_0 denotes initial resistance of filter and H resistance after passage of vol. V of water. Filtrability, denoted by F, is reciprocal of filtrability index. Filtrability F is number of seconds which are required for initial filter resistance H_0 to increase to value H, such that $H/H_0 = e$, veloc. of approach to filter being 1 fps. Among typical examples of filtrability measurements, tests show indexes of 0.695 and 1.02 for raw water from Barrow Res. of Bristol Waterworks strained through wire cloths, and 0.1075 and 0.075, resp., for 2 samples of Knott Hill Res.; values of I for 2 samples showing reduction of I (increase of F) produced by action of ozone. In deep sand filter necessary to deduct, from measured head loss H across filter, resistance of lower part of bed which does not enter into filtering action. Difficulty is to det. effective depth of filter for any case. If ineffective portion of filter denoted by a, then plotting of $\log(H-a)$ against V gives straight line when correct value of a is chosen. Slope of this line expresses filtrability of raw water with respect to filter, while initial value of resistance of upper depth of sand where $\log(H-a)$ is directly proportional to V can be taken as C_f, and represents depth of penetration into sand of solids resisted by filter. It can be shown that for fixed strainer

or filter:

$$H = \frac{mQC_f}{A} e^{nIQT/A}$$

$$T = \frac{A}{nIQ} \log_e \left(\frac{HA}{mQC_f}\right)$$

where H denotes loss of head across strainer fabric or across effective depth of filter at time T from start of run, at given temp.; Q is const. total rate of flow through strainer or filter; C_f is initial resistance of strainer or effective depth of filter (when T is 0) at given temp.; A is effective submerged area of filter or strainer; I is filtrability index of raw water measured on strainer or filter in use, I remaining const.; and T is time of run from commencement for C_f to increase to H. m and n are constants depending on units chosen. For H in in., Q in gph.(Imp.), C_f in ft. (for veloc. of approach of 1 fps.), A in sq.ft., and T in min., $m = 0.00053$ and $n = 0.00268$. For automatic strainer $H = \frac{mQC_f e^{nIQ/S}}{A}$ where S denotes speed of strainer. Where S is in sq.ft. per min. (and other factors are as above), m and n are as above. Head loss at any temp. can be converted from head loss at 50°F (H_{50}) from expression $H_t = \frac{60\ H_{50}}{t + 10}$ where H_t denotes head loss at t°F. and t denotes temp. in degs. F. For checking eff. of filters it is difficult to imagine any more sensitive test than that of measuring filtrability index of filtered water using fine sintered glass filter. Study of effect of primary sedimentation on pold. Poole Harbor salt water showed improvement of filtrability of 170% within first 15 min.—*H. E. Babbitt.*

Stellar Filters. Dean E. Colvin. Official Bul., North Dakota Water & Sewage Works Conf. **14**:2 (Dec. '46). Stellar Filter, new type of filter employing diatomaceous earth as filter aid, described. Comparison to sand filters given, and filtration rates, installation costs, and types of diatomite filters discussed. Savings in space and weight qualified diatomite filter for use by field units. Equally important benefit, however, was removal of chlorine-resistant organisms and all suspended solids by filtration through diatomaceous earth.—*P.H.E.A.*

High-Rate Water Filtration Meeting Practical Tests at Chicago. Anon. Eng. News-Rec. **139**:44 (July 10, '47). Special pretreatment measures and gradation of filter materials enable Chicago South District filtration plant to operate at rates as high as 4 gpm./sq.ft.—twice normal.—*Ed.*

Torresdale Filters Modernized. Elwood L. Bean & Robert J. Waters. W. W. Eng. **101**:32 (Jan. '48). Water level in Torresdale Presedimentation Basin at Philadelphia subject to wide tidal fluctuations, making it difficult to dose entering raw water at rate proportional to varying flow coming into basin. Authors describe ingenious control designed for regulating dosage to assure proper coagulation, pending constr. of new mechanical filters.—*Ed.*

Addition^ to St. Hyacinthe (Que.) Water Filtration Plant. Louis Crepeau. Wtr. & Sew. (Can.) **85**:4:20 (Apr. '47). Increased demand as result of war necessitated addnl. purif. facilities, peak consumption being somewhat more than 4-mgd. capac. of existing plant. Condition of latter improved and new independent 4-mgd. plant constructed, 2 being operated as unit. Each plant consists of low- and high-lift pumps, sedimentation basin, 4 rapid sand filters and clear well. Common to each is 12-mgd. mixing basin providing 48 min. retention. Water drawn from Yamaska R., through two 20" suction lines equipped with Nash Evacuator to prevent loss of suction. Two new low-lift pumps of 3- and 5-mgd. capac., resp., added to 4 existing 2-mgd. units. Three automatic Omega-type chem. feeders, for alum, activated C and lime, installed in new plant, and old manual dry feeders retained for emergency, as were old manual chlorinators, prechlorination and postchlorination being effected with new automatic equip. Old sedimentation basin, providing 2¼ hr. detention relined; new one provides 4½ hr. retention. New filters equipped with Wheeler bottoms and Palmer agitators. Combined air-water wash retained in old units. Three new high-lift pumps, 2 of 3-mgd. and 1 of 5-mgd. capac., each primed by evacuator. Total capac. of 2 clear wells 0.6 mil.gal. Power supply derived from 2 sources.—*R. E. Thompson.*

Pumping Station and Treatment Plant at Witharen. J. C. Keller. Water (Neth.) **31**:228 (Nov. 13, '47). Station consists of 3 deep well raw-water pumps, each connected through pressure line with individual prefilters. Raw water sprayed into filters of

classic constr., i.e., drainage in gravel beds. Drainage pipes serve also for backwashing, both with water and air. Filter material 1–3 mm. Water passes prefilter at rate of 6m./hr. Backwashing accomplished by intermittent use of water and air at rate of 25m./hr and 600 cu.m./hr (35 cu.m./hr/sq.m. of filter area) resp. Prefiltered water again sprayed on secondary filters and filtered at rate of 3m./hr. Backwashing at rate of 15m./hr and 600 cu.m./hr (17 cu.m./hr/sq.m.) for water and air. Since water still corrosive, sprayed for third time. Compn. of raw water: iron 7 ppm., manganese 0.4 ppm., free CO_2 20 ppm. Addn. of KM_nO_4 or lime too expensive.—*W. Rudolfs.*

Quick Filters. K. Werstadt. Paliva a Voda (Czechoslovakia) **27**:122 ('47). Article reports expts. carried out in water works of Geneva with rapid filters with special constr. of bottom.—*C.A.*

New Filtration Works and Pumping Station for the Metropolitan Water Board. Proposed New Works at Ashford Common, Ashford, Middlesex. Anon. Wtr. & Wtr. Eng. (Br.) **50**:405 (Aug. '47). Avg. daily supply '46–'47, 332 mil.gal. (Imp.). Indicated that for '47–'48 it will be 350 mgd. (Imp.). Filtration plant must be designed to yield 130% of avg. Peak demand of 455 mgd. (Imp.) may be expected. At present, plant can deal with about 315 mgd.(Imp.) with addnl. 45 mgd. from wells. Slow sand filters authorized for Walton and reconditioning of Hampton beds will increase yield by 26 mgd. by '50. Ashford Common site consists of 131 acres lying east of Queen Mary Res. Decided to provide plant on this site with output of 90 mgd.(Imp.). Normally raw water would be obtained from Queen Mary Res. Arrangements also made to take water from existing 72" conduit, Staines aqueduct, and proposed Wraysbury and Datchet reservoirs. First stage in purif. would consist of aeration, then battery of micro screens instead of conventional primary filters. Next stage would be through 32 slow sand beds, each about ¾ acre in area. After filtration activated granular carbon treatment followed by chem. treatment would be provided. Pumping station equip. should be driven by purchased electricity with 3 diesel alternators and 2 gas turbine alternators to form complete stand-by. Filtered water would be pumped into supply through two 48" mains and one 54" main. Estd. cost £4,290,000.—*H. E. Babbitt.*